THE AFTER TREATMENT OF WOUNDS AND INJURIES

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BY

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PREFACE

This book does not pretend to be a complete account of the principles and practice of orthopædic surgery. In it I have tried to give the results of the experience acquired during two and a half years' work in a Military Orthopædic Hospital, to state the principles which I have been led to adopt, and to give sufficient examples of methods and results to guide others in their practical work. The principles of the work are the same as the principles of the older civil orthopædic surgery. They depend upon three things, a knowledge of pathology, a clear appreciation of mechanics, and the realisation that the surgeon's aim is to restore function. Many new methods have appeared in military orthopædics, but in almost every case they depend upon the application of an old principle.

In Chapter II I have thought it well to describe the rational treatment of chronic sinuses of bone, perhaps the most frequent sequel of a wound, and the most important cause of delay in reparative work. I adopted the radical operation described from Prof. Broca's book and have found it most successful. It is now, I believe, generally adopted all over the country. Chapters III to X are concerned with the principles of treatment. Chapters XII to XVI deal with injuries to specific regions and contain many examples of actual cases. Chapters XVII to XIX give a very brief account of the methods of splinting, plaster-of-Paris work, and physical methods of treatment. A good practical knowledge of splinting and of the use of plaster of Paris is an essential part of the training of an orthopædic surgeon; without resource in these methods he is lost. Physical methods, massage, baths, electric treatment and exercises are usually left in the hands of specialists, but the surgeon should have a general knowledge of their methods and objects. Chapter XIX only pretends to indicate this in outline, to give a minimum that the surgeon must accept. A fuller knowledge is desirable, and for this books on the special branches of therapeutics must be read.

I am indebted, as are all orthopaedic surgeons of to-day, to Sir Robert Jones for the teaching of the principles of Orthopaedics, and for many of my methods. His energetic organisation and stimulation of orthopædic surgery during the war have alone made possible the work upon which this book is based. To my colleagues at Shepherd's Bush in all departments of work I owe many ideas and much that I have learnt from their work and from their criticism of mine.

R. C. E.

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CHAPTER I

THE PRINCIPLES OF REPARATIVE SURGERY

The ultimate aim of military surgery is to restore the functional utility of the damaged part of the body. From the military point of view the first aim is to restore the man to such a condition of full bodily strength and activity as will enable him to return to the fighting line. This may, or may not, be a possibility; if it is, such a restoration should be accomplished in the shortest possible time in order that man power may be economised. If, however, such a complete restoration is impossible, our next endeavour must be to enable the man either to resume some other military activity, or at least to return him to a position of useful activity in civil life. We must aim at improving the utility of every injured man by restoring the functional power of the damaged part so far as this is possible.

The treatment of war injuries is far more complex than is that of the injuries of civil life; not only are the actual injuries sustained themselves much more severe, but in addition they occur under such conditions as often make it difficult or impossible to secure cleanliness in the wounds. A septic infection of gunshot wounds appears so probable that the fact that the present methods of treatment have in many cases eliminated this complication must be looked upon as a veritable surgical triumph. The severity of the wounds and the supervention of sepsis are not the only factors which render the restoration of function difficult. The conditions of modern war involve a physical and mental strain which cannot but have a very important bearing upon the recovery of the wounded; in addition, the complexity of the wounds often necessitates very long periods of treatment in hospital. As the result of the severe nervous strain of the campaign and of the slowness of recovery from the wound the mental attitude of the soldier often becomes an important barrier to the rapid recovery of function. In carrying out our treatment we have first to overcome the physical and surgical difficulties, and then so to organise the surroundings of the patient as to overcome this mental attitude, and by a process of gentle and firm persuasion

to induce the man to use his damaged limb, and thus eventually to return him to a useful occupation in the Army, if this is physically possible, in civil life if it is not.

In the treatment of wounds and injuries the conditions met with are many and complicated: they may involve any or all of the skeletal tissues. We meet with extensive scars, the result of loss of skin, which are often adherent to the deep parts, often ulcerated or imperfectly healed. The muscles may be divided or separated from their attachments, or they may be paralysed by the division of their nerves; the tendons may be divided or destroyed or adherent. Injury of an important nerve may have left a whole limb, or limb segment, useless, or may produce pain of extreme severity and persistence. The bones may have been fractured and may be malunited or ununited, the joints injured and stiff or ankylosed. In some cases amputation has led to a final permanent loss, but not one that is always irreparable. In others a comparatively slight injury has left a complete functional disablement in the limb, due possibly to prolonged disuse, possibly entirely to the mental attitude of the patient. Amongst such a complexity of conditions every case must be considered as a problem in itself to be studied carefully in all its aspects before a decision is come to upon the line of treatment to be adopted.

The surgeon who is occupied in reparative work may perhaps be inclined to think that the conditions that he has to treat are indications of failure on the part of those who have been before him, and who have undertaken the care of the patient in the earlier stages; but he must remember the difficulties of treatment in such complex injuries under war conditions, he can only guess at the condition of the wounds in the earlier stages, and it is his duty to deal with the result which is before him and not to find fault with others who have done their best under conditions of which he can have no knowledge. If he finds that particular methods of treatment have regularly resulted in some special deformity or disability, he should call attention to the defects in this method with a view to its improvement. General criticism of a method is useful, but criticism of individual cases is to be avoided.

Briefly stated, the object of the orthopædic surgeon is to restore a maximum functional utility to the damaged part by the simplest and most expeditious methods. It does not follow that in doing this he should always aim at the correction of deformity along anatomical lines. The most successful surgeon is he who recognises quickly the essential point to be improved, and carries out the improvement by the simplest means. Perhaps the best example

of this is to be seen in the treatment of mal-united fractures due to gunshot wounds. In these cases careful study will often show that the disability is due to some associated condition rather than to the mal-union of the fracture. If this is so, an operation for the correction of the alignment of the bone will simply mean that the patient is condemned to another long period of treatment for his fracture without any ultimate improvement resulting, but if the mal-union is itself the important point it may be possible to correct the essential element in the deformity by some simple safe procedure such as a subcutaneous osteotomy, instead of undertaking the much greater task of remaking the fracture and attempting to secure a better alignment, the latter procedure being often attended by the risk of producing a recrudescence of a septic infection, whereas the simple osteotomy performed away from the site of the original injury is practically absolutely safe.

The procedures of orthopædic surgery may be shortly classed as follows :—

1. The repair by surgical means of the damaged part, so far as this is possible. This repair includes the suture of the skin, excision of scars, suture and repair of nerves, muscles, and tendons, restoration of continuity in bones in good alignment, and such surgical treatment of joints as will secure stability and mobility.

2. The replacement of functions which are definitely lost by the use of the remaining healthy parts by such means as tendon grafting, tendon fixation, and fixation of joints.

3. The restoration of function by methods of physiotherapy, including treatment by massage, movement, baths, and by gymnastic re-education, and including also the actual functional use of the limb in the course of active work.

4. The replacement of function by the fitting of an appliance such as an artificial limb.

The surgeon must himself follow and assist in all these methods of treatment, and should on no account confine himself to the operative side of the work. If he is to advise upon and carry out amputations to the best advantage for the patient, he must be himself conversant with the fitting of the artificial limb. If he transplants a tendon, he should himself supervise the subsequent re-education.

The rules of the orthopædic surgeon are simple. First, his aim should be to restore functional use; secondly, simplicity and safety are the criteria of the excellence of his methods; and thirdly, it is only by himself following out the completion of treatment that he can know the final results that he obtains, and thus can guide himself by them in subsequent cases.

CHAPTER II

THE TREATMENT OF CHRONIC OSTEOMYELITIS

Reparative work of all sorts is constantly hindered and delayed by the presence of an infected sinus. For example, operations for the success of which healing by primary union is essential are only possible after every sinus is finally and soundly healed and the area of operation thus rendered aseptic. Suture of a divided nerve is an operation which should be carried out at the earliest possible moment, but its success is jeopardised if suppuration occurs, therefore in all cases in which a nerve has been divided it is very necessary to get rid of the sepsis by the cure of any persistent sinus, and to get rid of it quickly and finally. The same may be said of operations for the suture or transplantation of tendons or the transplantation of bone, or even of simple osteotomy and osteoclasis. Where an operation on a joint has to be undertaken the absolute exclusion of a septic focus is essential. Where a sinus is present even simple massage and mobilisation of joints and tendons by manipulation, with or without an anæsthetic, may result in an exacerbation of the inflammatory process, a cellulitis arising and resulting in still further loss of tissue and in fresh matting of structures by inflammatory adhesions.

Even when a wound which has been septic has remained healed for a period of three months or more, it does not follow that healing is final and that there is no hidden focus of sepsis. Frequently when there has been a bone injury there remains deep in the wound a cavity in the bone lined by granulation tissue and containing a few drops of pus and perhaps one or more sequestra. The discovery of such a focus in the course of an operation leaves the operator to face the alternative of postponing the completion of the operation or of risking its failure through the supervention of a septic infection of the wound, and a failure in such a case may mean not simply that the desired result is not obtained, but that, because of an infection of the freshly exposed tissues, the whole local condition is rendered far worse than it was before.

Still another factor may endanger the result of a plastic operation

upon the deep tissues. The healing of many war injuries leaves a large and often adherent scar covered only with thin skin, the nutrition of which is comparatively poor. If such a scar is reflected in a flap there is a strong probability that its nutrition will fail completely, particularly if a hæmatoma forms beneath it. The scar will then slough or dissolve away, and an area will be left which must heal by granulation, and under which, for example, a bone graft may become exposed.

For these reasons, the presence of hidden sepsis and the danger resulting from a thin weak scar, it is often advisable to perform a preliminary operation before undertaking an operation of the magnitude of a bone graft or arthrosplasty.

In many cases of bone injury which have been treated at Casualty Clearing Stations by the most up-to-date methods, and in which healing has therefore followed in a comparatively short time, the apparent absence of deep sepsis is fallacious. Some small fragments of bone have really necrosed and remain enclosed in the tissues with a small amount of granulation tissue around. The foci are infected, the infection may be of low virulence, but if the wide area of an extensive operation wound is contaminated from them disaster may occur (Fig. 1).

It may be thought that these cases of persistent sinus will in time right themselves, that the sequestra will separate and come away or be removed by such a minor operation as curetting. This is true in a certain number of cases, and the occurrence of such cases too often leads surgeons to adopt an expectant attitude in all cases of bone sinus. In order to prove the fallacy of this attitude it is only necessary to consider the pathology of cases of chronic osteomyelitis, whether they be of the type resulting from simple infection of bone, such as is seen in civil practice, or whether they result from infection of a compound comminuted fracture such as is produced by a gunshot injury.

In osteomyelitis of non-traumatic origin there is originally an infection, with effusion which becomes purulent, under the periosteum, in the medullary cavity and in the Haversian canals.

The infection itself and the interference with the circulation result in the necrosis of a greater or less extent of bone, which lies subperiosteally, and at a comparatively early stage the stripped periosteum over this necrosed area commences to form new bone. The necrosed bone, which now gradually separates to form sequestra, is enclosed by new periosteal bone except at certain points (cloacæ) where the pus has forced its way to the surface or has been evacuated by incisions. The separation of sequestra takes a considerable time,

weeks or months, and during this time much new bone may form, so that by the time that the sequestra are loose and ready for removal they may be, and usually are, so enclosed that they cannot escape or be removed without some of the new bone being first cut away.

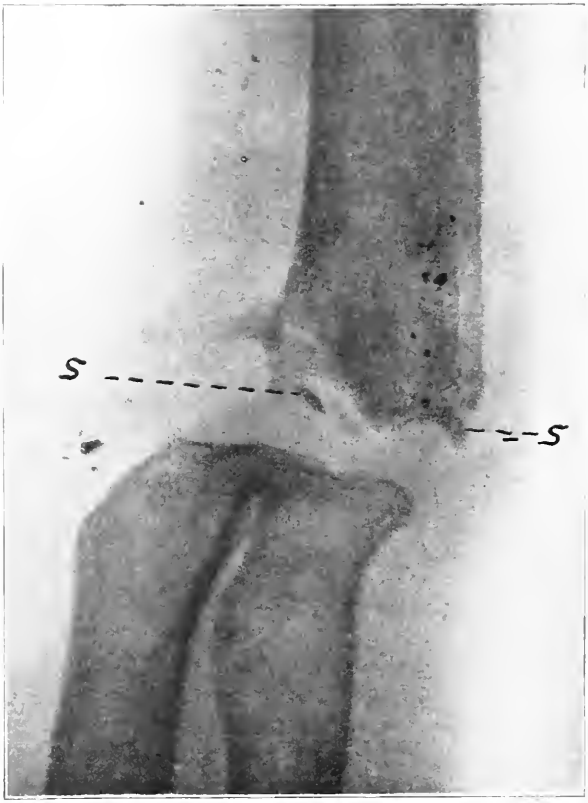

Fig. 1.—X-ray of an elbow joint, flail as the result of excision of comminuted fragments of bone soon after the occurrence of the wound. The wound healed in six weeks and never reopened, but an operation performed eighteen months later with a view to fixing the joint revealed the presence of two sequestra (*s, s*), each lying in a small pocket of granulation tissue. Cultures of the sequestra resulted in a pure growth of staphylococcus aureus. The operation upon the bones was postponed; the operation wound suppurated.

Fractures due to gunshot wounds are usually comminuted, a section of the bone often being broken up into tiny fragments. Necrosis of these fragments, even when they are completely detached from their periosteal attachments, does not necessarily occur; in fact, it is doubtful if such necrosis ever does occur apart from the supervention of sepsis. In gunshot fractures in which the entry

and exit wounds are small and which heal aseptically, necrosis is very uncommon, and operative experiments have proved that it is possible to transplant portions of bone which are devoid of periosteal covering without their forming sequestra. Therefore we must look to the supervention of sepsis as the usual cause of necrosis in gunshot fractures. Probably only a small proportion of the sequestra which are formed at a late stage in infected comminuted fractures represent entire fragments separated by the original injury; most

FIG. 2.

FIG. 3.

External and internal aspects of a sequestrum removed from a case of infected comminuted fracture of the shaft of the humerus. The upper, more or less smooth, edges represent the fractured surfaces; the lower, dentate and irregular, edge, the surface which has separated by ulceration from the rest of the shaft.

such sequestra show the jagged, dentate margin which proves that they have undergone gradual separation from the healthy bone, and it is usual to find sequestra which from their position and outlines can be proved to have separated from the ends of the shaft of the bone above and below the fracture.

In a comminuted fracture the periosteum may be extensively torn, and pieces of it may become interposed between the fragments, but usually a more or less continuous tube of periosteum remains between the ends of the main fragments. So that in a comminuted fracture where the intermediate fragments have been removed at

an early stage and a gap of an inch or more is thus left, it is not unusual to find that this gap is filled in time with new periosteal bone and the shaft thus reconstituted. I have seen a gap of one and a half inches in the femoral shaft thus filled up. When sequestra have formed they are liable to become enclosed by this new periosteal bone, and to become further embedded in the bone that is formed by the torn shreds of periosteum and by the osteoblasts of the exposed medulla. Therefore by the time that they are separated many of the sequestra will be so enclosed by new bone that escape is impossible. It will be necessary to remove them by surgical methods. In small bones the sequestra are of smaller size, and they are less likely to become massively enclosed, so that often they will escape or can be removed by simple curetting, but in large bones, particularly in the femur, the sequestra will in many cases be so enclosed that an extensive operation is necessary.

In any case much time will be saved by the removal of sequestra by a radical operation soon after they are separated, always provided that this can be done without starting an exacerbation of the sepsis and infecting fresh tissues. That this is possible by modern methods has now been amply demonstrated.

Investigation of Chronic Sinuses.

The usual reasons for the persistence of a sinus are either—

(*a*) The presence of definite sequestra, or
(*b*) The presence of a cavity whose walls are rigid, being composed either of bone or of scar tissue of such density that they cannot fall in and so close the cavity, or—
(*c*) The presence of metallic or other foreign bodies, such as cloth or non-absorbable ligatures. Amongst these, pastes such as BIPP, which some surgeons are in the habit of inserting in quantity into wounds or sinuses, must be remembered. The presence of such a foreign substance, particularly in a track whose walls are rigid, will effectually prevent final healing.

In investigating such a sinus the first step should be the careful use of a probe of small calibre but with a definitely blunted end. A few minutes' investigation with a probe, persuasion rather than force being used, will in a very large proportion of cases demonstrate that the track enters a cavity or tunnel in the bone, a sequestrum often being felt. The mobility of the sequestrum is not always easy to determine, nor is it of very great value, for it is rare to find that the sequestrum that can be felt is the only one present. In judging

of the separation of sequestra time must always be the most important consideration. In all bones, except the femur, tibia, skull and ilium, three months may be taken as a sufficient period for the separation of sequestra. In the femur and tibia, where sequestra of large size are suspected, it may be safer to allow a longer period up to six months.

X-ray examination is the next important step. Plates should be taken in two planes at right angles to one another, if this be possible, and much assistance may be gained if the surgeon inserts a probe to the bottom of the sinus before the plates are taken. A stereoscopic photograph with the probe *in situ* is of the greatest assistance, the fact that the probe lies in the cavity or tunnel in the bone being often made evident. Sequestra as a rule throw a shadow which is denser than that of healthy bone. But sequestra are not the only matter of importance in an X-ray photograph. An endeavour ought to be made to picture from the stereoscopic photograph the exact conformation of the damaged area of the bone, the relation of the bone fragments to each other, the arrangement of the outlying callus and the presence of cavities or tunnels.

In some cases information may be gained by the injection of a bismuth paste into the sinus,[1] the paste being injected in a melted condition and allowed to solidify in the sinus. Several injections on successive days are necessary to make sure that the whole track has been filled. An X-ray photograph will then show the extent to which the paste has penetrated. There is very small risk of any symptoms of poisoning arising from such injections because the paste is only injected into a sinus with indurated walls through which absorption does not occur.

Radical Operation on a Sinus.

A large proportion of persistent sinuses are due to the presence of sequestra or to a cavity in the bone. Those due to silk ligatures, cloth, etc., may be distinguished by the fact that the probe does not reach or enter bone, but it is not possible to make certain upon this point. It is not unusual to find that a sinus is kept up by superficial necrosis or by a small cavity in the bone, even when the evidence yielded by the probe and by X-ray photographs has failed to show any bone lesion; it is therefore as well in operating upon a sinus to

[1] The following formula may be used—

Bismuth subnitrate . .	30 parts
Cera alba	10 ,,
Paraff. flav.. . . .	70 ,,
Formaldehyde . . .	1 ,,

liquefied by heat.

be prepared for any eventuality and to expect that in most cases the operation will become one for the radical removal of sequestra and the closure of septic cavities or tracks in the bone.

The patient should therefore be fully anæsthetised, and no attempt should be made to operate upon a sinus under a short anæsthetic such as that given by simple gas or ethyl chloride. The operation may last a few minutes, but it may equally well last an hour. Wherever possible a tourniquet should be applied. The improved view of the field of operation thus yielded simplifies the operation and shortens it, and enables the exploration of septic tracks in the bone to be made much more thoroughly.

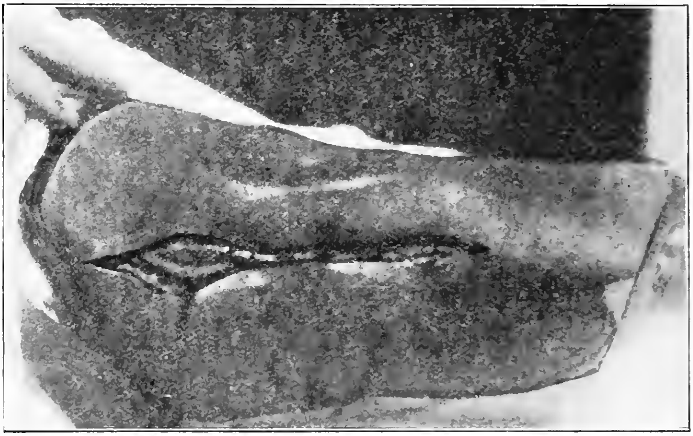

Fig. 4.—Radical Operation upon a Septic Cavity in the Femur. Incision encircling the entire sinus and old scar on the outer side of the bone.

The first step is again to probe the sinus carefully. If it does not extend to bone it should be opened up with a scalpel and thoroughly curetted, ligatures and other foreign bodies being looked for. If a secondary track is found, it must be equally carefully exposed. If a foreign body has been found and if the sinus does not reach down to the bone, it may then be left to granulate. But if the surrounding tissues are so indurated that they will not fall together, then all this scar tissue should be cut away until healthy tissue is exposed, the skin edges freed by undercutting, the tissues treated with BIPP, as described later, and the wound sutured, a drainage tube being inserted for a few days. Where the operation has been performed as a preliminary to a later operation upon a bone, joint, tendon or nerve, this removal of scar tissue should be carried out as a routine.

When the sinus leads to bone a radical operation upon the damaged

part of the bone should be undertaken forthwith. The incision must be made of sufficient length to enable the bone to be exposed above and below the injured site, even if this necessitates an incision ten or twelve inches long. It is not necessary or always advisable to explore the bone through an incision at the site of the sinus. Each bone should be explored from the aspect which gives the best exposure; for example, the shaft of the femur is best exposed by an incision on the outer side. It would obviously be very difficult to get a sufficient exposure with safety by following up a sinus on the inner side of the femur or in the popliteal space. If necessary a double incision must be made; thus, to gain a good exposure of the lower third of the femur, it may be advisable to make a second incision on the antero-internal aspect in addition to that on the outer side. Wherever an incision is made, the excision of the cutaneous opening of the sinus and of any adjacent adherent scar should be a part of the routine.

The incision having been made down to the bone and through the periosteum, the latter should be stripped back from the whole circumference of the bone, the whole of the soft parts and the scar tissue being lifted away by force, the large curved bone levers, used for plating, being most useful for this purpose. The stripping back of the periosteum should be commenced at the site of healthy bone above and below the area of the fracture, working towards the latter. At the site of the fracture the scar tissue is nearly always densely adherent and difficult to separate.

The next step is the thorough exploration of every track and cavity in the bone, starting with the largest and most obvious. A close watch must be kept for the opening of any tunnel; when one is found a probe should be inserted into it and the whole of the outer wall of the tunnel chiselled away, the floor of the tunnel then being scraped or chiselled until it lies flat and no longer makes a groove. The wall of every cavity must be similarly cleaned and the edges of the cavity bevelled down from above, below and the sides, so that the surface remaining is as flat as possible with no deep pits, and consists of healthy bone or callus. No track or depression lined with granulations must be left. If a cavity remains so deep that it cannot be laid quite flat without endangering the strength of the bone a wide groove should be chiselled towards it from above and below, so that it is converted into a gutter into which the soft tissues can fall, and in which there is no risk of the subsequent enclosure of sequestra. When a track passes right through the centre of a bone it may not be advisable to remove one of its walls completely, as this would leave the bone too weak. In this case the track should be

converted into a large hole through the bone surrounded by healthy tissue. The edges of this hole on the accessible side should be thoroughly well bevelled down with the chisel. The wide opening of such a central track will very often be immediately justified by the discovery of a sequestrum on its inaccessible side, which could only have been removed by the enlargement of the track.

The very extensive removal of bone in this radical procedure may often appear to endanger the strength of the shaft of the bone at the site of operation. But no hesitation should be allowed on

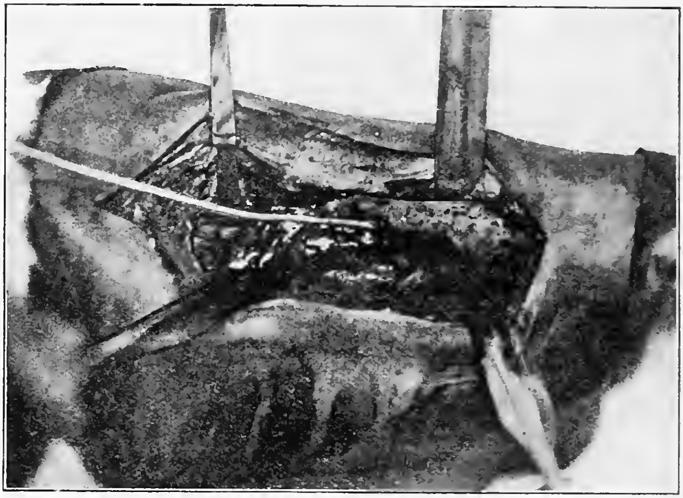

Fig. 5.—Radical Operation upon a Septic Cavity in the Femur.

The skin has been undercut and reflected, scar tissue excised, and the whole affected area of the bone exposed, large flat levers being inserted behind it. The probe is inserted into the main cavity.

this account. It may be necessary to refracture the bone, a procedure which is less serious than might appear, because a bone which refractures during this proceeding is often one in which union was insufficiently strong and in which refracture might take place as the result of slight traumatism.

A brief description of the objects of this part of the operation may assist the operator in the details of his procedure, for no two cases are alike, and the course pursued must always depend upon the conditions found at the time of the operation. The objects are—

1. To open up all tracks and sinuses and to leave no sequestra.

2. To remove all granulation tissue from the bone or callus upon which it lies.

3. To leave no possibility that superficial sequestra which may

form as the result of sepsis after the operation can become enclosed in callus.

4. To leave no cavity with rigid walls of bone, callus or dense fibrous tissue which cannot be filled by the falling in of the soft parts.

The next step in the operation is to secure that the muscles can fall in, cover the bone and sink into any gutter or cavity that is left. This is done by cutting away scar tissue freely, removing particularly the track of the old sinus. If necessary (and it usually is necessary)

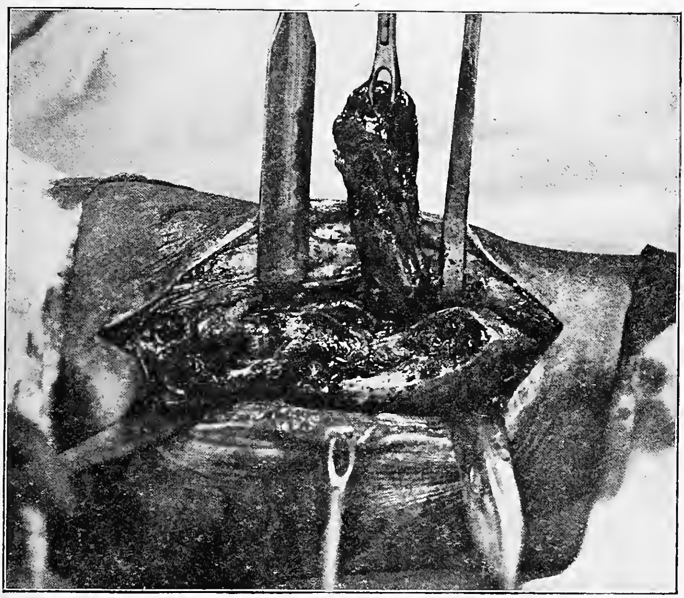

Fig. 6.—Radical Operation upon a Septic Cavity in the Femur.
The roof of the cavity has been removed and the whole bone thoroughly cleaned. A flap of muscle (vastus externus) has been cut for insertion into the cavity.

a flap of muscle is then cut so that it can fall into the cavity of the bone. Wherever possible this flap should be cut in such a way that the muscle fibres retain their function to some extent. For example, in the middle third of the femur a flap is cut from the vastus externus, the upper part of the muscle being cut through, freed, and laid into the cavity, the lower part being left continuous with the rest of the quadriceps extensor. In cutting the muscle flap it is a good thing, if possible, to keep a layer of periosteum on its deep surface, as this, lying against the bone cavity, will assist in the formation of new compact bone and so strengthen the injured site. Due care must always be taken in cutting the flap to avoid injury to the important

nerves and vessels. The bone having now been prepared, the muscle flap freed and all scar tissue removed, the skin should be freed by undercutting where necessary so that suture is possible. The entire wound is then swabbed out with methylated spirit and carefully dried. BIPP is then taken and rubbed into the entire surface of the wound, bone, muscle and subcutaneous tissue, and skin being smeared with it. Plenty of paste should be used, but very little should be left in the wound, the greatest care being taken to rub away every particle of the BIPP that can be got away by rubbing with a gauze swab.

If masses of BIPP are left in the wound there is an undoubted

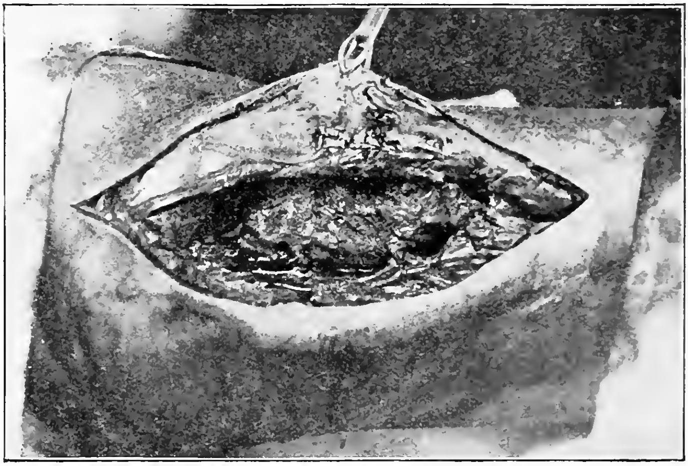

Fig. 7.—Radical Operation upon a Septic Cavity in the Femur. The wound has been treated with BIPP and the muscle flap stitched into place with catgut.

liability for symptoms of poisoning to arise. Apart from this, BIPP acts as a foreign body and serves to keep open the sinus.

The muscle flap should then be laid into the cavity and fixed there with an easily absorbable catgut suture; if necessary a drainage tube is inserted and the wound sutured. The suture shown in Fig. 8 is a very useful one for closing these wounds in which the skin edges have a great tendency to invert. A dressing is applied, the limb bandaged firmly and the tourniquet removed. The dressing is left in place from two to eight days. If there is no rise in temperature the dressing may be left the full time, the tube and stitches then removed, and the tube track left to granulate. If there is much rise in temperature it may be necessary to dress earlier and to remove, clear, and reinsert the tube.

In most cases the greater part of the wound heals by first intention, a sinus remaining only at the site of the tube. This sinus may persist for a month or two and small superficial sequestra may escape

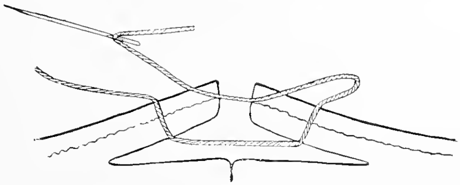

Fig. 8.—Mode of Insertion of Skin Sutures.

The needle, threaded with silkworm gut, is passed deeply through both edges of the skin three-quarters of an inch from the margin, then returned through the epithelial margin. The suture must not be tied too tightly.

from it. Should the track persist after three months it will probably require re-exploration. It will then be found either that a track or sequestrum has escaped notice at the first operation, or that a cavity has been left into which the soft parts could not fall, or that a

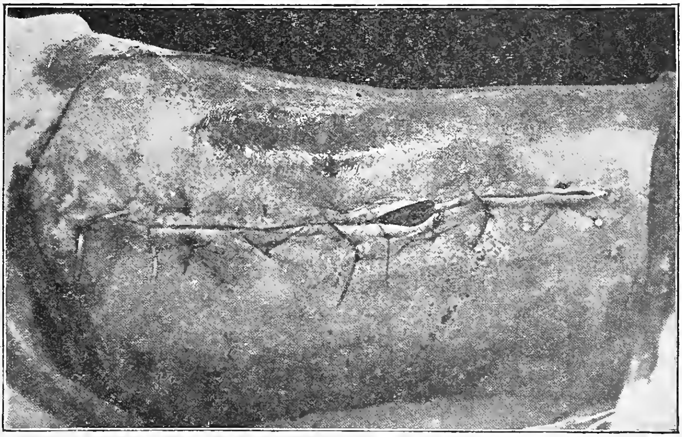

Fig. 9.—Radical Operation upon a Septic Cavity in the Femur.

The wound has been sutured with drainage.

new sequestrum has formed which is too large or too much enclosed to escape.

The essential part of this operation is the complete exploration of the bone and the removal of all sequestra, the eradication of all cavities and tracks in the bone, and the freeing of muscular tissue so that it can fall into place and leave no cavity with rigid walls. The method of treatment with BIPP is that which I have so far

found to give the best results in subsequent healing, but the use of other antiseptics and of other methods of after treatment may eventually be found to give better results. It is reasonable to give

Fig. 10.

Fig. 11.

Radical Operation upon a Septic Cavity in the Femur.

X-rays of the case upon which the operation shown in Figs. 4, 5, 6, 7 and 9 was performed, before and after operation. In Fig. 10 the cavity on the outer side is seen, in Fig. 11 the bone has been rendered quite smooth and clean.

a trial to any new method of treatment of an infected wound in these cases.[1]

[1] I have recently obtained good results by washing out the wound with a solution of Malachite green 1 in 100 in rectified spirit.

Preliminary Operations.

Closely analogous to this radical operation on a sinus is a preliminary operation which it is often necessary to carry out before attempting such a procedure as the insertion of a graft to repair a gap in a bone, or an operation which aims at securing a new mobile joint. Two reasons for undertaking the preliminary operation have already been given, viz. the necessity for getting rid of extensive, thin adherent scars, and the frequent presence of hidden septic foci in or in connection with the bone. There is still a third reason, that often the amount of deep scar tissue embarrasses the operation and, in the case of a bone graft, by poor vascularity, endangers the life of the graft. If it is not removed by a preliminary operation it will probably have to be dissected away before the bone graft can be laid into place.

This preliminary operation should be carried out under the same conditions as the radical operation on a sinus; that is, under full anæsthesia and if possible with a tourniquet applied. But if the presence of the tourniquet is likely to hinder the freeing of the skin, the cutting of flaps and the suture of the wound after the removal of an extensive scar, it should be dispensed with.

The first step is the removal of the scar, the incision being carried around in healthy skin and the whole scarred area cut away. Then the deep scar tissue should be dissected away as far as possible, due regard being paid to tendons, vessels and nerves. It must not be forgotten that where extensive scarring has occurred a nerve may have been displaced from its normal position; for example, in an operation in the elbow region as a preliminary to a plastic operation on the joint the ulnar nerve may be found densely involved in scar tissue and much displaced. If necessary in such a case the nerve may be exposed at a higher level where it is normally situated in healthy tissues, and dissected down through the scar, the dense fibrous tissue around it being all removed.

Next, if the bone has been damaged, this must be explored. In the case of an ununited fracture each end of the bone should be cleaned and the scar tissue between the ends removed entirely. Sequestra or pockets containing a drop of pus may be found either at the bone ends or in the intermediate fibrous tissue. In an old comminuted fracture, which has united, the area of the fracture should be examined, particularly if the skiagram shows any evidence of a cavity or sequestra. If a sequestrum or cavity lined with

granulations is found, the bone must be dealt with as described in the last operation.

The bone having been explored, scar tissue removed, muscles and tendons freed, the skin is next prepared for suture. In most cases undercutting is all that is necessary; if this, however, is insufficient to allow approximation of the skin edges, a flap must be cut from the neighbouring part where there is most skin to spare, and brought round to relax the tension.

If a septic focus has been found in the course of the operation, the wound should be treated with methylated spirit and BIPP and sutured with drainage. If there is no septic focus the wound may be sutured completely.

Where a considerable area of skin is lost and the surface cannot be covered by turning a flap of skin from the neighbouring part the alternatives are—

1. To shorten the limb. This is often the best way in loss of substance in the forearm, particularly in the neighbourhood of the wrist. In such cases, however, it must form a part of the final bone operation.

2. By utilising a cuff or flap of skin from the abdominal wall. A method only available in the upper limb in situations which can be approximated to the abdomen. A flap is cut from the abdominal wall, being left attached by one or two broad pedicles. It is sutured in place over the raw area and cut free from the abdominal wall three weeks later when it has had time to become vascularised in a new site.

3. A massive skin graft may be taken from the abdomen or thigh. The graft is completely freed from its attachment, its deep surface being very carefully cleaned of all fat. It is transferred to its new site and sutured. Before fixing such a graft the tourniquet, if used, should be removed, and the wound must be very carefully dried, as the formation of a hæmatoma beneath would almost certainly prevent the graft from living.

CHAPTER III

MAL-UNION OF FRACTURES

Gunshot fractures differ from simple fractures chiefly in the fact that they are often extensively comminuted, that there is considerable loss of substance either immediately at the injury, or remotely, from necrosis, and that they are in a large proportion of cases infected. Even in simple fractures it is exceptional to get the fragments in such a position that alignment in every direction can be said to be perfect; that is to say, it is only in very exceptional cases that an X-ray photograph of a fracture will show the fragments in such perfect position that the spicules of bone actually interlock. It must not be considered that a fracture is mal-united because perfection such as this has not been obtained. Mal-union should only be considered to be present when the position in which the fragments have united is such as to affect the functional utility of the limb.

Varieties of Mal-union.

The practical result after union of a fracture should be considered as dependent on the alignment of the main fragments of the bone, ignoring the position of smaller fragments which, while they may affect the amount of callus and the shape of the region of the fracture, will have no bearing upon the functional utility of the limb.

The displacement of the main fragments upon each other may be in one or other of several directions. In the first place the two fragments of a bone—for example, the femur—may lie parallel with each other, but not in the same straight line; this constitutes *lateral displacement or antero-posterior displacement* according to the plane in which it occurs. Lateral and antero-posterior displacement may be of considerable importance in appearance, but of very little importance to function. In a lateral displacement of the lower fragment of a fractured femur firm union may take place by buttresses of callus formed by stripped periosteum. The result will be a very serviceable limb, provided that the displacement is purely lateral and that there is not also an angulation of the fragments.

Longitudinal displacement of the fragments upon each other necessarily implies a shortening of the limb extending to the amount of

the overlap. This displacement is, of course, almost invariably accompanied by a lateral displacement also. Shortening of the limb may affect the utility of the limb comparatively little, and again be important chiefly from the æsthetic point of view. This is particularly so in the upper limb, where shortening of the humerus has very little effect upon the strength and utility of the arm. The muscles which pass over the whole length of the humerus, the biceps and triceps, soon undergo adaptive shortening, and work as freely and strongly over the shortened humerus as they did over the normal one. In the lower limb shortening is of more importance, because it necessitates the wearing of a high boot, but even here the importance of shortening is often exaggerated, and many of the functional disabilities ascribed to this cause are really due either to an angulation at the seat of the fracture or to some damage to the other part of the limb. In minimising the functional results of shortening I do not wish to imply that every possible effort should not be made to avoid it, but simply to indicate that drastic treatment is not as a rule justified by the presence of uncomplicated shortening of a limb.

Angular displacement of the fragments of a fracture is of very great importance. In the upper limb angulation of the humerus forwards may affect the movement of the elbow joint in the following way. If the lower fragment is inclined backwards at an angle of 30° to its normal direction, then extension of the elbow will be excessive by this amount (30°), and flexion will be diminished by the same amount. Similar angulation in the femur backwards, a very common one, will result in an apparent hyperextension of the knee, throwing a tremendous strain upon the hamstring muscles and often rendering walking upon the limb impossible until a suitable support has been fitted. Angular deformity in this direction in the upper limb affects the apparent movement of the elbow in a way that constitutes a slight disability, but the same angulation in the lower limb, where weight-bearing is the important function, renders the limb practically useless. In a similar way angulation in the humerus to one side or the other alters the axis of movement of the elbow joint and either abolishes or increases the carrying angle at the elbow, a deformity which is ugly but not very disabling, but an angulation in the femur inwards or outwards produces genu valgum or genu varum, either of which interferes greatly with walking and throws a strain upon the knee which must eventually damage the joint.

In *axial displacement* the lower fragment of the fractured bone is rotated on its longitudinal axis in relation to the upper fragment. A common example of this displacement occurs in fracture of the

upper half of the radius; the upper fragment is supinated by the biceps muscle, the lower fragment is pronated by the pronator teres, and it is not uncommon to see this fracture treated by immobilisation in the pronated position, so that the fragments unite with the upper supinated and the lower portion partly or fully pronated. The result is to abolish full supination of the forearm, for by the time

Fig. 12.—Mal-union of a fracture of the lower end of the femur. The lower fragment is displaced backwards and angulated upon the upper, so that an apparent hyperextension of the knee is produced.

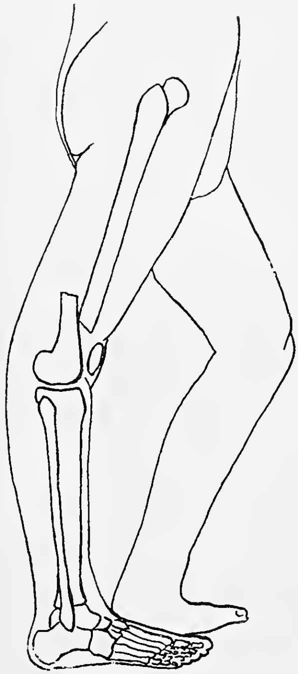

Fig. 13.—Diagram of the position of the fragments.

that the lower fragment is half supinated the upper fragment has reached the position of full supination and can rotate no further. When a fracture of the tibia has been treated by a Thomas's splint without the knee being fixed securely, an axial rotation of the lower fragment of the bone upon the upper is not uncommon. The foot is slung in the vertical position, but the knee is allowed to fall outwards so that the upper segment of the limb, including the upper fragment of the tibia, rotates outwards upon the lower; the result is a very disabling inversion of the foot (see Figs. 14 and 118).

In examining a case of mal-union of a fracture, the important points for consideration are—

1. Is the functional disability in the limb brought about by the faulty union of the fracture?

FIG. 14.—Photograph of plaster casts of a leg before and after osteotomy. The tibia had been broken into three pieces, of which the middle piece formed a small bridge joining the upper and lower fragments. The lower fragment was internally rotated upon the upper and angulated with a concavity forward. There was also a severe talipes equinus. The deformity was corrected by a simple subcutaneous osteotomy of the lower fragment below the line of the fracture and by lengthening of the tendo Achillis.

2. If so, what particular element in the deformity is producing the disability?

3. What is the simplest means of overcoming this element in the deformity?

It must be remembered that nearly all these gunshot fractures are accompanied by sepsis and by extensive injuries of other parts. Frequently when we look closely into a case of mal-union we find that the disability is due, not so much to the mal-united fracture as to accompanying stiffness of neighbouring joints and to scarring or disuse of neighbouring muscles. Even if we conclude that the fracture itself is the cause of the disablement we may find that the real trouble is something that is beyond repair, such as actual loss of bone at the site of the fracture. When, however, it is clear that the disability is largely due to angulation of the fragments on each other, or to overlapping, or to axial displacement, we should then recognise which is the important point and consider what will be our easiest way of correcting it.

Treatment of Mal-united Fractures.

The compound fractures which result from war wounds are slow in consolidating; sometimes many months elapse before the fracture is firm enough to withstand the full weight of the patient without bending. Whilst this is no doubt the cause of mal-union in many cases, it is also important as giving us an opportunity of correcting

some cases of mal-united fracture without operation. When the fracture is united only by callus so soft as to be capable of being moulded by pressure, the site of the fracture is usually tender; if this tenderness on pressure is found, it is worth while attempting to straighten a fracture with angulation deformity by properly applied pressure, either upon a splint or in plaster of Paris.

Whenever a fracture is fully consolidated the only possible method of correction is by refracture, either by osteoclasis or by osteotomy.

It must again be emphasised that these gunshot fractures have almost invariably been septic and that latent sepsis is very commonly present in them even when they have been healed for several months. If a pocket of granulation tissue is opened in the course of an operation, this latent sepsis will almost certainly infect the whole wound, making it necessary for the patient again to go through the prolonged and painful treatment of a compound septic fracture. It might be thought that the risk of lighting up sepsis could be lessened by straightening the bone by simple refracture without any incision, but this method has proved to be both objectionable and dangerous. In the first place the actual site of the fracture produced is uncertain, the bone may not break exactly at the intended point, and correction of the deformity may therefore be poor. In the second place, when the refracture occurs through the site of the old injury, any pocket of granulation tissue which is present is almost certain to be torn open and the hæmatoma that forms at the site of the fracture thus becomes infected and produces an abscess. In fact, osteoclasis of these mal-united fractures very commonly leads to a recrudescence of sepsis.

Practically, then, there are two methods of operative treatment for mal-united fractures—simple osteotomy and reconstruction of the original fracture.

Simple Osteotomy.—Simple osteotomy is the method to be adopted whenever it will suffice to correct that element in the deformity which is considered to be producing the disability. It has the very great advantages that a simple subcutaneous operation can be carried out at a distance from the site of the original injury, and that, therefore, asepsis can be relied on with certainty. Whenever possible, the standard osteotomies of surgery should be adopted. For example, in the lower limb a fracture of the neck of the femur, with adduction deformity, or with eversion, can be corrected by a simple transtrochanteric osteotomy. A fracture either of the lower end of the femur or of the upper end of the tibia which has resulted in genu valgum can be corrected by MacEwen's supra-condylar

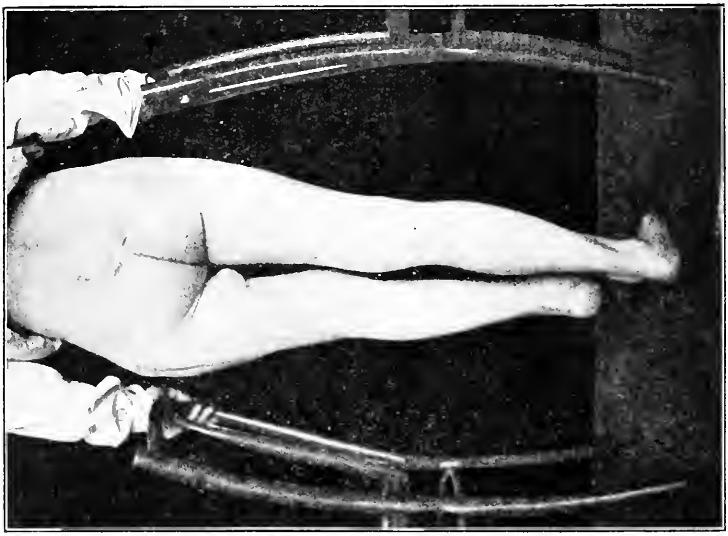

Fig. 15.

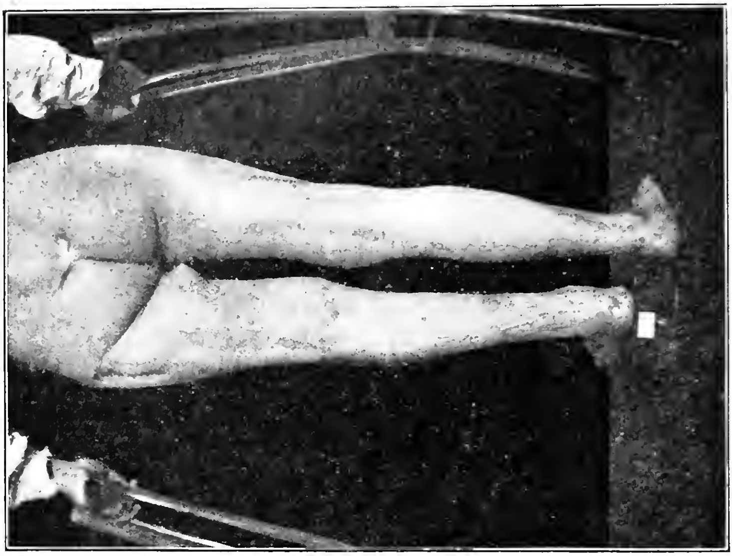

Fig. 16.

Fracture of the femur immediately below the great trochanter with mal-union, causing adduction of the hip and great shortening. The deformity was partly corrected by a simple subcutaneous osteotomy through the great trochanter (Jones's method). The shortening was reduced from $5\frac{1}{2}$ inches to 2 inches. Fig. 16 shows the final result.

osteotomy. The inversion of the foot which results from rotation of the lower fragment of the tibia can be corrected by a simple osteotomy of the shaft of the tibia (Fig. 14). The osteotomy should be carried out with a fine-bladed osteotome, or an Adams's saw in the ordinary manner. The deformity should be corrected and the limb fixed in the correct position in plaster of Paris immediately.

Reconstruction of the Fracture.—In certain fractures it is impossible to get good correction by carrying out a simple osteotomy; it is necessary to reconstruct the original fracture and to correct the deformity at that point. When the original fracture has been simple, there need be no hesitation in using this method. The

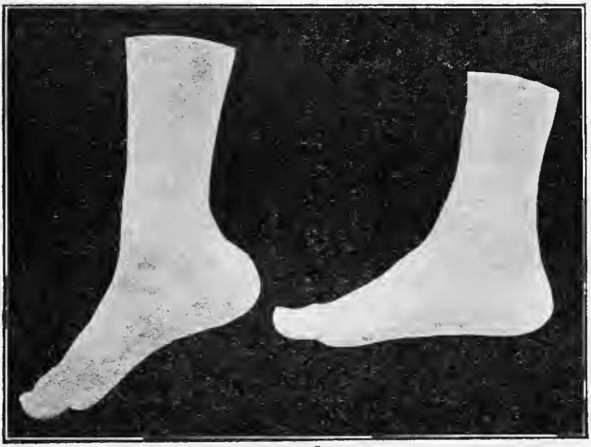

Fig. 17.—Pott's fracture mal-united, with severe valgus deformity and backward displacement of the foot. Corrected by reconstruction of the fracture. Plaster casts of the foot before and after treatment.

fracture for which it is most necessary, and in which it is most successful, is Pott's fracture. Mal-union of this fracture with a bad valgus deformity and a displacement of the foot backwards is very common. The fracture can be reconstructed by the removal of a small wedge from the base of the internal malleolus and by oblique osteotomy of the lower end of the shaft of the fibula. With a wrench the foot can then be completely replaced into its correct position in relation to the tibia (Fig. 17).

It may occasionally be necessary to operate on a fracture of the shaft of a bone such as the femur for the correction of mal-union by remaking the fracture. When this is done a very wide exposure of the bone will be necessary, involving an incision through the muscles, perhaps seven or eight inches in length; it will then be

necessary to divide the old point of union and to remove all callus, keeping a very close look-out for any pocket containing granulation tissue or sequestra. The ends of the medullary cavity of the bone in each fragment should be opened. Reduction of the fragments into proper position may be easy if the shortening has not been great, but if there has been an overlapping of two or three inches it will usually be necessary to angulate the fragments on each other until their ends can be got to engage. By then bringing them gradually into a straight line, a powerful leverage is exerted which reduces the shortening and ultimately ends in good position. Such an operation of reconstruction of a fracture of the shaft of the femur, with its extensive incision and severe manipulation of the fragments, with its risk of fresh sepsis, and with, in addition, a certain risk of delayed union resulting, is one that is not to be recommended or undertaken lightly; in my opinion it is very seldom that a mere longitudinal displacement, even if it causes a shortening of two or three inches, can justify such an operation. Only when the disability is due to angulation of the fragments at the seat of the fracture do I consider that such an operation is desirable.

CHAPTER IV

DELAYED UNION AND NON-UNION OF FRACTURES

Delayed union and non-union of fractures due to gunshot wounds are more common than in simple injuries; this is due chiefly to the loss of bone which results from the removal of comminuted fragments, or from the necrosis of portions of the bone as the result of sepsis. Whilst delayed union is very common, absolute failure of union occurs comparatively seldom and is practically confined to certain special bones. In the lower limb non-union is very rare. I have so far seen only two cases of absolute failure of union in the femur, and none in the tibia. The essential cause of non-union is the loss of substance, including a complete severance of the periosteum, so that there is no osteogenetic tissue to bridge the gap. In the lower limb such a loss is as common as in the upper limb, but the severe injuries with which it is associated are more apt to lead to amputation; moreover, a gap in the bone tends to be closed by approximation of the fragments by the pull of the longitudinally disposed muscles unless this is prevented by (1) a dependent position of the limb, as in the humerus, or (2) the resistance due to the presence of a parallel bone, as in the radius or ulna. For this reason a gap in the femur tends to close unless an unwise amount of extension is applied.

Non-union is most likely to occur in the humerus, in the radius, in the ulna and in the tibia and fibula. When union is delayed in the femur and in the tibia appropriate mechanical treatment will usually be all that is necessary, except in rare cases; for example, in considerable loss of substance in the tibia, when the fibula may keep the fragments apart. Non-union in the fibula is quite unimportant, as large sections of this bone may be missing without any resulting disability. Therefore the problem of treating true non-union most often arises in the humerus, in the radius, and in the ulna.

Treatment of Delayed Union.

I. When delayed union is due to a septic infection—for example, where there is a persistent sinus leading to a sequestrum, or, after

healing, a sequestrum can be seen in the X-ray—the first treatment must be operative upon the lines laid down in Chapter II. Whether

Fig. 18.—Ununited fracture of the tibia, with intact fibula. The latter bone has kept the fragments of the tibia apart and caused them to bow inwards.

Fig. 19.—The result of an oblique osteotomy of the fibula in this case. The fragments of the tibia have come into contact, and the bowing is to a large extent corrected.

a sequestrum has been found or not, the chances of the recrudescence of sepsis are so great that treatment of the wound with BIPP and drainage for a week are always advisable.

II. When sepsis has been eliminated the principles to be adopted

are, (*a*) approximation of the bone ends, (*b*) functional use of the limb in a suitable appliance, (*c*) the use of accessory measures, such as passive congestion.

If it is not possible to secure approximation of the ends of the bone by simple mechanical means, an operation for this purpose must be undertaken. There are then two possibilities; either we may treat the case as one of non-union and carry out a major operation, such as refreshing the bone ends and fixing them by means of a bone-graft, or else we may confine ourselves to simply clearing the ends of the bone, freeing them from scar tissue and levering them into apposition, refreshing the ends of the fragments if necessary. It is generally worth while to complete the major procedure, fixing the fragments together by means of a bone-graft, but it must be remembered that this procedure is only safe when absolute asepsis can be relied upon. In some cases a comparatively simple operation will suffice. For example, in fractures of the tibia with a small loss of substance, the fragments do not come into good apposition because an intact fibula holds them apart. In such a case a simple oblique osteotomy of the fibula may be performed; the leg may then be fixed in a walking appliance, when the weight of the body will help to bring the ends of the tibia in contact, and union will usually result (Figs. 18 and 19).

Functional use of the limb is certainly one of the best ways of assisting union. It is best illustrated in the lower limb, for which many forms of ambulatory splints have been designed; these are all modifications or elaborations of the Thomas caliper splint, which remains the best, simplest and cheapest appliance for the purpose. It consists essentially of a ring which surrounds the top of the thigh upon which the tuberosity of the ischium rests, of two lateral bars which extend from the inner and outer sides of the ring to the heel of the boot into a socket in which they fit, and of a few simple straps which secure the limb in the splint (Figs. 129 and 130). The splint is adjusted to a case of ununited fracture of the femur so that the ends of the bone are just in contact and most of the weight is borne by the lateral bars of the splint, a small proportion of it only being borne by the bone itself. In such a splint the patient can walk with ease, and in almost every case union will result in the course of three or four months.

In non-union of the tibia a shorter appliance is all that is necessary. A moulded leather case enclosing the tibia from its upper end to just above the malleoli with lateral steels fitting into a socket in the boot is the best; this protects the bone and enables it to carry a large proportion of the weight (Fig. 20). In the upper

limb no apparatus has yet been devised that will allow of the use of the arm and keep the fragments of the humerus in apposition. Undoubtedly the dependent position is a very important cause of the frequent occurrence of non-union in the humerus.

In the forearm, non-union of the radius or ulna is in most cases due to the fact that the fragments of the bone are kept apart by the length of the parallel bone, which has either not been fractured, or else has united with little or no loss of substance; therefore, in the upper limb every case must be considered as one of true non-union rather than of delayed union, except those in which the fragments are in contact but the callus remains unossified. These are best treated by enclosure in a simple moulded leather splint with or without a steel elbow joint. The use of the limb in this splint will usually result in the completion of union.

FIG. 20.—Walking appliance consisting of a moulded leather splint with lateral steels to a socket in the heel of the boot, applied to the case shown in Figs. 18 and 19.

A very valuable accessory in the treatment of delayed union is the use of *passive congestion*. This method was originally introduced by Thomas many years ago. The fractured area is congested by the fixation of indiarubber bands above and below, drawn just sufficiently tight to render the area a dusky purple colour. The congestion should be kept up on the first occasion for half an hour; it should be repeated daily, the time being increased until treatments lasting about two hours are reached. Percussion of the congested area with a heavy body such as the head of a metal dumb-bell will sometimes assist; this combined treatment was introduced by Thomas and called by him "treatment by damming and percussion." It is particularly useful in delayed union of the humerus.

It is difficult to define the exact point at which delayed union

becomes non-union. As already pointed out in certain cases, particularly in the forearm, when there is much loss of bone, it may be evident from the first that union cannot occur. In other cases, more particularly in the lower limb, it is best only to accept the case as one of non-union, that is, as one that will require a major operation, when a period of treatment lasting about four to six months upon the lines above indicated, leaves the bone still ununited.

Non-union of Fractures.

When a fractured bone remains definitely ununited in spite of treatment, either an operation for fixation by bone-grafting or by plating must be carried out or else a supporting appliance must be worn permanently. Evidently the operation will be the better method whenever it is possible, because if it is successful it yields a final and permanent cure. Practically the cases for which such operation is required are those of non-union of the humérus and of the forearm bones (usually of only one of these). Only very occasionally is such an operation required in the long bones of the lower limb. Flail joints, in which there has been considerable loss of bone at the articular ends, come into a different category and will be considered separately.

The methods available for operation on ununited fractures are—

1. Shortening the bone by refreshing the ends, overlapping, and suturing either with an absorbable ligature such as catgut or Kangaroo tendon, or with a non-absorbable ligature such as wire.

2. Refreshing the ends of the bone and fixing them by means of plates.

3. Refreshing the ends of the bone and fixing them by means of a bone-graft.

In deciding on one or other of these procedures, it is most important in non-union of fractures due to gunshot wounds to bear in mind certain points in the pathological anatomy of the conditions present. In the first place, there has usually already been much loss of bone, so that if overlapping is the method adopted the eventual shortening will be great. It is usually necessary to overlap at least 1 inch, or $1\frac{1}{2}$ inches, in order to get a secure fixation of the fragments to each other. In the forearm, when one bone only is ununited, overlapping cannot be carried out without excising a length from the other bone and shortening that also. In the second place, a bone which has been fractured and has remained ununited for months will be found to be much rarefied. This is, to a certain extent, an objection to overlapping; it is much more an objection to the method of bone-grafting by a sliding graft which will be mentioned

presently, for the graft will consist of light fragile bone, and secure fixation will consequently be very difficult.

In the third place, over the termination of the fragments there is much scar tissue, the periosteum may be destroyed, if not it is scarred and adherent and the medulla of the bone is closed at the extremity of each fragment and is usually sclerosed so that it is practically absent for a distance of half to one inch beyond this. Without entering into the controversy as to which parts of the bone and periosteum are chiefly concerned in the regeneration of bone, we may accept that this function exists in the osteoblastic layer of the periosteum, and in the endosteal lining of the medulla, that it exists also in the endosteum lining of the marrow spaces of the cancellous bone and of the Haversian canals of the compact bone; in other words, it exists wherever there are osteoblasts, and its activity is roughly proportionate to the number of osteoblasts in the tissue. Therefore in order to start a healthy osteogenetic process, it is advisable to cut away the scarred end of the bone up to the region where the periosteum is healthy and the medullary cavity present.

This last point will explain the objection to simple refreshing operations and to refreshing with fixation by a plate in ununited fractures in which there is much loss of bone. In order to render union probable it is necessary to cut away bone until the whole of the scarred end of the fragment is removed. There may be no objection to this in the humerus; it is, however, obviously impossible in the forearm bones, as it would necessitate shortening of the companion bone, thus depriving us of the splinting action of this bone during the period of healing and also shortening the forearm. This shortening, apart from its æsthetic objections, may seriously interfere with the proper balance of the delicate wrist and finger muscles.

Apart, altogether, from these practical objections to the fixation of an ununited fracture by means of a plate, many surgeons feel an instinctive dislike to the insertion in a bone of a foreign body which does not undergo absorption. There is no doubt that the insertion of screws into bone tends to increase the absorption of bone in their immediate neighbourhood. Areas of rarefication can almost invariably be seen about the screws in X-rays, and, quite apart from any risk of infection, there is little doubt that the presence of a foreign body does not assist in promoting healthy osteogenesis.

The bridging of the gap in the bone by means of a bone-graft is obviously the best method of treatment of these ununited fractures if it can be carried out with a reasonable prospect of success. It

has been amply demonstrated that this is possible provided that certain general rules are obeyed; briefly stated, these rules are as follows:—

1. The possibility of sepsis must be absolutely eliminated; if necessary, the area of operation must be explored at a preliminary operation, to make sure of its cleanliness. The actual fixation of the graft must be carried out with the most careful aseptic technique.

2. The graft must be massive, strong and amply long; it must overlap each bone fragment by at least $1\frac{1}{2}$ inches, if this is possible.

3. The fractured ends must be trimmed and prepared in such a way that the graft can be fixed subperiosteally, and so that it is in contact with healthy medulla when the shaft of the bone is concerned, or with the healthy cancellous tissue of the epiphyseal end.

4. The graft must be firmly fixed in close contact with the fragments; if possible, two sutures should be used at each end. All intermediate and surrounding scar tissue must be dissected away, and, if possible, the graft should lie in and be covered by healthy muscle.

The actual method of grafting that I now prefer is fixation by a lateral graft of massive character, taken as a rule from the subcutaneous surface or anterior border of the tibia and fixed subperiosteally to the side of the fragments of the bone; fixation being made by boring both bone and graft and transfixing with strong catgut, which is then wound twice round the bone and tied.

Technique of Operation for Bone-grafting.

1. *Preparation of the Site for the Graft.*—No tourniquet should be used either for the part of the limb from which the graft is being taken, or for the part to which it is being transferred. The fractured bone should be exposed by the most accessible route, a long incision being made, and any scars in the line of this incision being excised. If in retracting a flap a thin scar is lifted up, it also must be excised; if this is not done, it will probably slough and interfere with the healing of the wound. The incision should be long enough to expose each fragment of bone over a distance of three or four inches, or as far as the neighbouring joint. The skin edges should be retracted just far enough to enable strips of sterile linen to be attached with the tissue forceps, thus shutting off the skin entirely from the area of operation. This being done, the incision is deepened until the bone is reached. Taking the upper fragment first, the periosteum should be incised well above the free end, at a level at which it is presumably healthy; this periosteum is then stripped

from the bone until a bone lever can be slipped completely around the shaft; working from this point downwards, the whole bone is stripped of periosteum and scar tissue. Where the periosteum is healthy it can be elevated with a blunt instrument, but near the extremity of the fragments when scar tissue is reached a few cuts with the knife will be necessary. The lower fragment is then cleared in exactly the same way, commencing distally where the bone is healthy and working towards the fractured extremity. The intermediate scar tissue is then dissected away or divided until the two fragments can be easily stretched or rotated until they lie in normal relationship to each other. In the case of one of the bones of the forearm, this dissection should be carried out until the styloid processes at the wrist are in their normal relationship and until the lower fragments can be fully pronated and supinated.

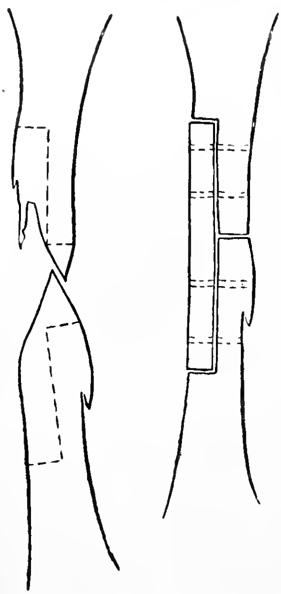

Fig. 21.—Method of grafting in ununited fracture of the humerus. Each end of the bone is cut away until healthy bone is exposed; the fragments are then brought into contact and secured by a strong lateral graft, being sutured by the method shown in Fig. 22.

The next step is to remove the extremity of each of the fragments of the bone. If, as in the case of the radius, the intention is to bridge a considerable gap with a graft and thus to restore the bone to its original length, then it is unnecessary to cut off the whole of the scarred end of the bone; but in other bones—for example, in the humerus—it is better to shorten the bone, bringing the two fragments into contact and using the graft as a lateral support. In this latter case we hope for an eventual osseous union between the upper and lower fragments themselves; therefore it is essential to cut away the scarred ends of the fragments until healthy bone-tissue is exposed. Having trimmed the ends of the fragments, the next step is to cut away the side of each fragment so as to leave a flat surface upon which the graft can be fixed. The corresponding side of the upper and lower fragments must first be identified, carefully rotating the limb into an accurate position. Raise the upper fragment on a broad flat retractor and saw off with the motor saw nearly half the thickness of the bone for a distance of at least one and a half inches from the extremity. This should be carried out in three cuts, (1) up along one side of the bone, (2) a parallel cut along the

opposite side, (3) a cross cut across the top. One assistant must hold the retractor and keep all tissue out of the way, the second must pour saline solution upon the saw to prevent over-heating. In using the motor saw the cut should not be carried out too hurriedly; if the saw is worked too rapidly it is difficult to prevent heating and charring of the bone, and this undoubtedly prevents the healthy growth of bone subsequently. The saw-cuts being completed, a few strokes with a fine osteotome will complete the separation. The lower fragment is then raised with a retractor and prepared in exactly the same way.

When one of the fragments consists only of the epiphyseal end of the bone it is undesirable to saw off one entire surface. Two parallel cuts should be made into it at a distance apart equal to the width of the graft. A cross cut is made joining these and the piece of bone thus marked out removed with an osteotome; the graft can then be fitted into the slot thus cut out and securely fixed. The surface for the fixation of the graft being now prepared, the limb is manipulated into the desired position and a measurement taken of the exact length of the graft required. The wound is then packed with gauze and covered while the second stage of the operation is being carried out.

2. *Cutting the Graft from the Tibia.*—The incision should expose the tibia for a distance two inches longer than that of the graft required. It is best to expose the bone by turning a flap inwards so that the vertical part of the incision is over the tibialis anticus muscle and no scar is left over that part of the tibia from which the graft is taken. The reflection of this flap leaves the fascia over the tibialis anticus and the periosteum over the tibia exposed. The graft to be cut is marked out upon the periosteum of the tibia by cutting with a scalpel. The most massive graft can be obtained from the anterior border of the tibia; from this a graft one-half to three-quarters of an inch wide and three-eighths of an inch thick can be cut without seriously weakening the bone. By a vertical incision through its fascial sheath close to the crest of the tibia and by the use of a periosteal elevator the tibialis anticus is separated from the external surface of the tibia over the whole length of the incision. With the motor saw a cut is made into the medulla of the tibia along its subcutaneous surface, over the required length and at a distance of one-half to three-quarters of an inch internal to the crest, the saw being kept at right angles with the subcutaneous surface. Then a second longitudinal cut is made into the external surface of the bone three-eighths of an inch behind the crest, the saw-blade being kept parallel with the subcutaneous surface of the

bone, cross cuts are made at the upper and lower end, and then, with a few strokes with the osteotome, the graft is separated.

Instead of using this method the graft may be taken entirely from the subcutaneous surface of the tibia by making two parallel cuts either with a twin-bladed saw or with a single saw. The cuts should be three-eighths of an inch apart, and the anterior one should not be nearer to the crest than this distance; they must be deepened until the medullary cavity of the bone is opened, and then joined by cross cuts at either end. The graft is lifted by the insertion of fine-bladed osteotomes along its side and gently levering with them. It is a little more difficult to cut and to lift this graft, and its strength

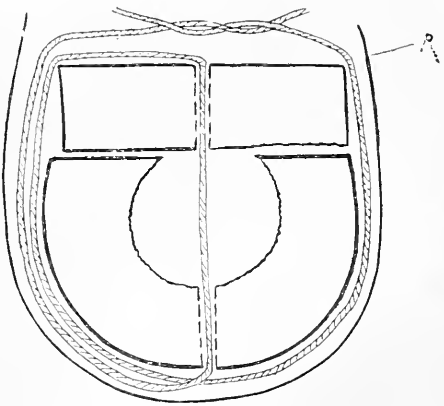

FIG. 22.—Method of suturing a lateral graft in place. The graft and bone fragments are drilled and transfixed with catgut, which is then wound round them and tied. *p*, periosteum overlying the point of contact of graft with fragment.

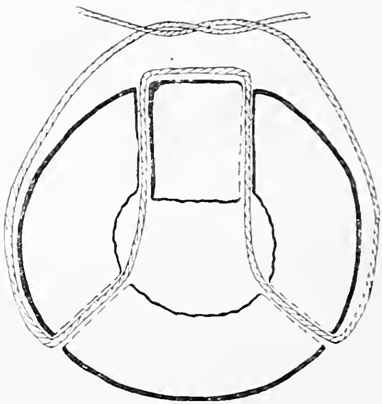

FIG. 23.—Method of suturing an inlay graft. The bone is drilled in two places and the catgut passed and tied in the manner shown.

is slightly less than that of the graft taken from the crest of the tibia; it has, however, the advantage of carrying with it the endosteum, which possesses undoubted osteogenetic powers. As far as the tibia is concerned the removal of a graft by either method appears not to weaken the bone, and the disturbance of the tibialis anticus muscle by the first method has no ill effects. In general a graft taken from the crest of the tibia is better when fixation by a lateral graft is being used; one taken from the subcutaneous surface is better for inlaying.

The graft is lifted and carried direct to the site to which it is to be fixed; suturing of the wound in the leg being left to an assistant. It is only necessary to suture the skin, no deep stitches and, as a rule, no ligatures being required.

3. *Fixation of the Graft.*—It is better to transfer the graft direct from the tibia to the site where it is to be fixed; it is unnecessary to put it in saline solution or to allow it to touch anything except the forceps which are used to carry it. It is at once laid in place against the upper fragment and the two held together with a pair of lion forceps, or other bone-holding forceps. With the motor drill both bone graft and bone fragment are pierced in two places, through each hole a piece of 30-day, No. 3 chromic catgut is passed; each end of the catgut is passed round the bone, and the ligature is then securely tied. It is advisable to pass the catgut with forceps without using the fingers; a curved suture-passer will facilitate this. The tying of the ligature can, however, only be performed securely with the fingers, but that part of the catgut that remains embedded in the wound need not be fingered.

Fig. 24.—Graft for ununited fracture of the radius. The upper end of the graft is fixed laterally to the shaft of the radius, the lower end is inlaid into a slot cut in its lower extremity.

The graft being thus securely fixed to the upper fragment, it is brought into proper apposition with the lower fragment and pierced and sutured in the same way. When the lower fragment consists only of the epiphyseal end it may only be possible to use one suture, but additional security is given by fitting the graft into a slot in the way already described.

The soft parts, including the periosteum, are allowed to fall into place over the graft, and the muscles are drawn together with a few catgut sutures; the periosteum on the upper and lower ends will not completely cover the graft, but it will cover the lateral points of contact of the original bone with the graft, and by the early production of

GRAFT INSERTED INTO THE TIBIA FOR THE LOSS OF THE SHAFT AS THE RESULT OF OSTEOMYELITIS, IN A GIRL OF SIXTEEN.

FIG. 25.—The condition of the tibia before the insertion of the graft.

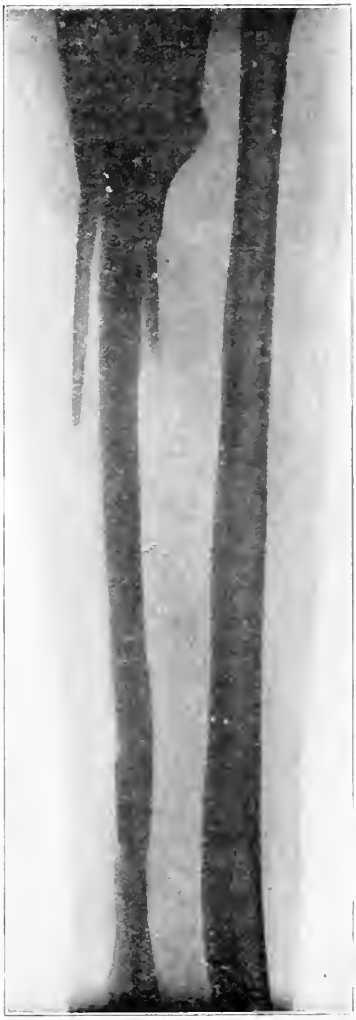

FIG. 26.—Six weeks after the insertion of a graft 10 inches long taken from the crest of the opposite tibia.

GRAFT INSERTED INTO THE TIBIA FOR THE LOSS OF THE SHAFT AS THE RESULT OF OSTEOMYELITIS, IN A GIRL OF SIXTEEN.

FIG. 27.—Two and a half years after the insertion of the graft.

FIG. 28.—Five years after the insertion of the graft. The new tibia is becoming restored to its normal shape.

subperiosteal callus at these points the graft soon becomes securely fixed. The skin may be sutured by any method, inversion being carefully avoided. If the graft is strong and firmly fixed it should be possible to trust to a comparatively light splint for the first ten days after the operation. In the forearm the application of anterior and posterior splints for this time is usually sufficient: then when the stitches have been removed the limb may be fixed in plaster of Paris. For the humerus more secure fixation is necessary. It is better to fix the whole arm and chest in plaster of Paris at the time of operation.

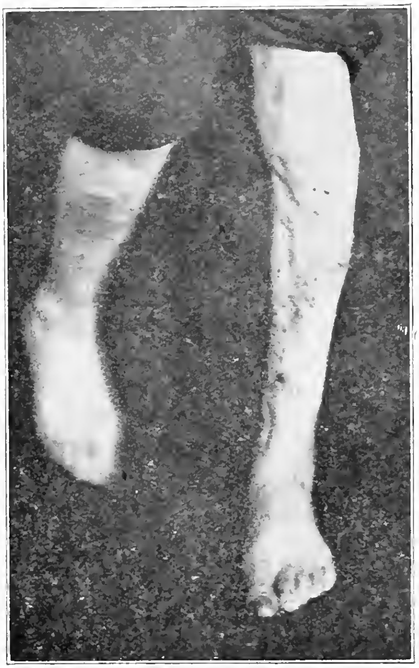

FIG. 29.—The tibia illustrated in Figs. 25 to 28 five years after the operation for bone-grafting. The patient is able to stand and walk upon the leg without external support, as shown in the photograph.

Inlay Graft.—Fixation with an inlay graft is exactly similar to the method already described except that instead of cutting off one side of each of the fragments of the bone, longitudinal slots are cut into the bone by two parallel saw-cuts, the medullary cavity being opened. The graft is cut from the subcutaneous surface of the tibia also by two parallel saw-cuts; it is fitted into the slot that has been prepared for it, and fixed as shown in the diagram. I have used this method considerably, but find that it is more difficult than the lateral graft, particularly for small bones such as the radius and ulna. In addition, the lines of contact of the graft with the bone into which it is fixed are not so certain to be covered with periosteum, so that the early production of callus at this point is not secure. For these reasons I have come to prefer the lateral graft, except in exceptional cases.

Sliding Grafts.—In this method a long slot is cut in the upper fragment and a short slot in the lower one; the piece of bone removed from the upper fragment is used to bridge the gap, being fixed in the slots of both fragments. This method was originated by Albee for grafting recent fractures; it is unsuitable for use in the un-

united fractures of war wounds, because the graft is taken from a bone which is rarefied from disuse and is therefore very fragile, and also because in most cases the graft obtainable is too short to bridge the gap and to get a secure hold at each end; to do this with a gap of one inch, a graft at least four inches long is required; such a graft can but seldom be cut from the upper end of a fractured bone in the upper limb.

Grafts from other Bones.—Some surgeons like to use grafts taken from the ribs. The whole thickness of the rib may be removed and used as a graft, or the upper half of the rib may be taken, the lower half being left, so that the intercostal vessels and nerves are left undisturbed. The ribs are rather fragile for use in grafting the long bones of the limbs; they are, however, very useful for grafts upon the skull.

For special purposes the whole thickness of the fibula, either the middle or upper part of the shaft, or upper end including the head, may be used as a graft; no functional disability follows excision of the fibula, provided that the lower three or four inches are left. Parts of the ilium may also be taken for special purposes when grafts of a particular shape are required. Again, there is no ill effect following the removal of a portion of this bone.

CHAPTER V

ANKYLOSIS OF THE JOINTS AND STIFF JOINTS

The affections of the joints that result from gunshot wounds of the limbs and from the severe simple injuries so often seen in military surgery present a very complicated pathological picture. Deformity of the bones produced by a fracture, the formation of new bone, scarring in the skin, muscle and periarticular tissue, and of the capsule of the joint itself, have all to be considered, as well as intra-articular changes, such as damage to the joint surfaces by injury or by sepsis. In addition to these, loss or paralysis of muscles, and those changes, possibly vascular, possibly partly vascular, partly trophic, which we class as ischæmic changes in muscles, seriously affect joint movements, and finally there are the disabilities classed as functional, due either to simple disuse or to a neurosis which produces paresis or spasm of a muscle or of a group of muscles. When the possible factors in the causation of a disability are so numerous and so complicated it is specially important that, before setting out upon a scheme of treatment, the surgeon should study carefully the nature of the condition that he has to treat, should endeavour to form as clear as possible a conception of the pathological lesion, and should from this arrive at his opinion as to the functional condition at the attainment of which he aims. In this, as in every branch of surgery, individual experience must count for much, nevertheless by following certain lines of argument certain fundamental conclusions can be arrived at with comparative ease.

Pathology of a Damaged Joint.

In endeavouring to form a picture of the pathology of a damaged joint the chief points to be considered are—

1. The site and nature of the original injury to the skin, soft parts and bones, the track of the projectile and the structures likely to have been injured.

2. The evidence of present or past septic complications in the joint or in the periarticular tissues or at a distance. Damage to a joint by suppuration within it, or around it, or in and around

important muscles which move the joint, is a self-evident cause for subsequent stiffness. The importance of sepsis at a distance is less easily understood. In a simple fracture of the humerus with musculo-spiral paralysis it is possible to splint the hand and fingers in the extended position for long periods without producing much resultant stiffness in the joints or adhesion of the tendons, but when the compound fracture is very septic the application of a similar splint for a comparatively short period without removal may cause stiffness of the fingers that will take a considerable time to overcome. Probably in these cases there is a mild distant septic involvement of the tendon sheaths and periarticular tissues, which gives evidence of its presence only in a moderate œdema, but which gives rise to a subsequent fibrosis which is the cause of the stiffness.

Fig. 30.—Gunshot wound of the knee joint with damage to the deep surface of the patella. Movement from almost complete extension to flexion to the right angle returned. Exploratory operation showed the deep surface of the patella roughened and the cartilage eroded; a piece of cartilage lay loose in the joint. The operation resulted in a slight increase in the flexion and in a feeling of greater security, probably due to the removal of the loose body.

3. A consideration of the present clinical condition of the limb, including the site and the nature of the scars, alterations in contour of the limb, the evidence of loss of substance or of deep scarring, the condition of the muscles (loss of substance, scarring or paralysis or spasm), the shape of the bones, the range of movement of the joint, the freedom of this mobility, the presence of grating on movement and of pain, the nature of the obstruction at the limit of movement in each direction, whether there is a definite limit as by a bony block or hard fibrous obstruction, or whether movement is limited by less dense fibrous tissue or by muscle spasm, and finally the presence of abnormal mobility.

4. Investigation by X-ray plates, if possible, taken in two planes, noting the appearance of the joint surfaces, whether these are smooth and undamaged, or interrupted by a fracture, or irregular from septic complications, the alignment of a fracture in the neighbourhood of the joint, the presence of displaced fragments which may hinder movement either mechanically or by interference with muscular

action, the presence of callus which similarly affects movement and of new formation of bone in the muscles around the joint.

5. If necessary, examination of the joint movements whilst the patient is under an anæsthetic. This may be necessary as part of the preliminary investigation, but more often it will be possible to carry the preliminary investigation so far that examination under an anæsthetic can be used both as an assistance in the final diagnosis and also as part of the treatment, further treatment (under the anæsthetic) consisting of either simple movement of the joint through a definite range (which may or may not be the full normal range), or alteration of position with fixation in a new position, or open operation, according to the conception of the pathological condition present that the surgeon has formed.

Classification of Stiff Joints.

Judged by the information yielded by such investigations and considerations, stiff joints may be classified as follows :—

1. *Simple Functional Disabilities*, the joint surfaces being normal. the alignment of the bones (if fractured) sufficiently good, any sclerosis of the periarticular tissues or of the muscles or intermuscular planes being absent. In these cases the stiffness is due to either—

(*a*) Habit, as, for example, when the hand is held stiffly after painful wounds of the forearm;
(*b*) Weakness of certain groups of muscles;
(*c*) Spasm of certain groups of muscles, such as is often seen in simple wounds of the forearm and hand.

In the first two groups the range of movement is normal, in the third the range of movement in the direction which will stretch the spastic muscles is limited. In all these cases if movement is neglected in the early stages, adhesions either around the joints or in the tendon sheaths are likely to develop; the case will then come under the next group.

2. *Slight Periarticular Adhesions*, where the range of movement is only slightly limited, there being also as a rule weakness of certain of the muscles moving the joint. When the disability is due to this cause a careful examination, testing the full range of movement, will be necessary to determine the cause. In certain joints, more particularly in the lower limb, a slight restriction of full movement may cause very considerable disability. The best examples of this occur in those derangements of the knee in which, following a simple

injury, the joint is weak, gives way in certain positions and becomes filled with fluid whenever the adhesions have been stretched. Cases of this sort will be specially described under disabilities of the knee and foot.

3. *Severe Periarticular Adhesions* in which there is obvious limitation of movement, such as occurs in the knee joint in cases of simple

Fig. 31.

Fig. 32.

Antero-posterior and lateral views of a fracture of the humerus extending into the elbow joint. The lateral view shows a little new bone formed around the olecranon. There was a limited range of movement in the joint, further movement being painful and restricted by muscular spasm. Treatment by all forms of physiotherapy failed to increase the movement.

fracture of the femur low down, and in many cases of compound fracture of the femur.

4. *Sclerosis of the Capsule of the Joint*, sclerosis of the muscles above or around the joint and adhesion of the muscles to the capsule and synovial membrane. These cases are common as the result of compound fractures which have been very septic, the sclerosis resulting from the tracking of septic material in and around the muscles and around the joint. Stiffness of the knee from this cause after a

compound fracture of the femur is a common condition and one very difficult to treat.

5. *Alteration in the Joint Surfaces*, either by a fracture which has extended into the joint, or by inflammatory changes which have caused erosion of the cartilage. In the latter class of case it may be difficult to distinguish between rigidity of the joint due to muscular action, which continues as long as the inflammation is active, and the stiffness which finally results from the changes which have occurred within the joint.

6. *Blocking of Movement by Callus* around a fracture in the neighbourhood of a joint and by new bone formed in the muscles and encircling the joint. The latter condition is specially liable to occur around the elbow joint. As a rule this encircling bone is the result of a myositis ossificans of traumatic origin, and it is again important to distinguish between the limitation of movement which is due to the inflammation of the muscle and that which later results from the purely mechanical effect of the new bone. This encircling myositis ossificans can arise as the result of septic infection, as is shown by the following very instructive case.

A man who had lost his lower limb through the thigh came under my care at Roehampton and was found unfit for an artificial limb because the stump was fixed at the hip joint in a position of 60° of flexion and slight abduction. An X-ray photograph showed a mass of new bone passing from the great trochanter to the back of the ilium. A careful investigation of his history revealed the fact that prior to amputation the patient had suffered from pyæmia and that a metastatic abscess had been opened in the buttock of the affected side, a tiny scar remaining. Operation showed that the mass of bone represented the whole of the gluteus medius muscle and was firmly fixed to the great trochanter and to the ilium; it was dissected out and chiselled away from its bony attachments. When it had been removed the hip joint at once became mobile, and massage and stretching restored practically perfect mobility.

7. *Intra-articular Fibrous Ankylosis*, as, for example, when there has been an evident septic infection of the joint which has been drained, but the joint surfaces have been kept apart, or when a limited excision has been performed and bony ankylosis prevented.

8. *Bony Ankylosis*.—This is a condition the diagnosis of which must be guarded. The only absolute proofs of bony ankylosis are—

(*a*) Inspection of the union at operation.

(*b*) The evidence in a skiagram of the existence of continuous pressure lamellæ of bone, passing right across the joint line.

and continuous with the lamellæ of the bones above and below.

Apart from these absolute tests the following will give information that is reliable—

(*c*) A complete absence of movement when the joint is forced by the surgeon either with or without an anæsthetic.
(*d*) The absence of pain when the joint is forced.
(*e*) The absence of any joint space or line in an X-ray.

As a rule a joint, which when forced without an anæsthetic is painless and fixed, and when forced with an anæsthetic is absolutely immobile, is fixed by bone. But it has fallen to the lot of most surgeons to diagnose bony ankylosis on clinical grounds in a joint that has subsequently recovered some mobility.

9. *Angular or rotatory union of fractures.*—If the humerus has been fractured in its lower half and the fragments united with an obtuse angle backwards, then if the elbow joint really moves to its full extent the apparent range of movement of the joint will be abnormal. When the elbow is really fully extended it will be apparently hyper-extended to an extent corresponding with the angle of mal-union of the humerus. When the elbow is really fully flexed it will be apparently imperfectly flexed to a corresponding extent. Similarly if a fracture of the radius is united with the upper end supinated and the lower pronated, supination will (for practical purposes) be incomplete and pronation may be excessive.

The Attitude of a Fixed Joint.

When a joint is absolutely fixed, as when the ankylosis is bony, it will be evident that fixation in certain positions gives the maximum of utility, fixation in other positions gives a limited use for certain purposes only, fixation in other positions leaves the joint practically useless. Thus in the knee fixation in the fully extended position gives the maximum of utility for standing and walking, a moderate degree of flexion renders the gait worse, flexion to a right angle renders the limb useless.

For this reason certain standard positions of the joints are fixed upon as those in which fixation of each joint should be secured when such fixture is inevitable. The standards adopted are as follows—

Shoulder Joint.—Abduction at 60° with slight forward flexion, the forearm being directed forwards and slightly inwards when the elbow is flexed. If the scapula is mobile its movement will allow

the arm to be adducted to the side and abducted beyond the right angle, it will also allow the hand to be brought across the body.

Elbow Joint.—For most occupations the best position is at about an angle of 110°; this suits both clerical work and also most manual occupations. It does not, however, allow the hand to be brought up to the mouth or to the back of the head. If both elbows are fixed one should be at 110°, preferably the right, the other should be at about 60°.

Forearm.—A mid position between pronation and supination, such that when the elbow is at the side and flexed to a right angle the palm of the hand is in the sagittal plane.

Wrist Joint.—Extension to 45°, *i. e.* the position attained when the fist is closed, the thumb lying over the second phalanges and the forearm and fist laid flat upon the table.

Hip Joint.—Flexion to 25° with the thigh vertical, neither abducted nor adducted, and the patella pointing forward, the foot pointing slightly out, provided that the limb is not shortened. If the limb is shortened the hip should be abducted to an extent sufficient to compensate for this. The slight flexion is to enable the patient to sit comfortably. When the limb is shortened it should be abducted to such a point as will make the two limbs apparently the same length when the sound one is adducted and brought parallel to the affected one. This abduction may be used to compensate for shortening up to about $1\frac{1}{2}$ inches; if carried beyond this it will cause too much tilting of the pelvis.

Knee Joint.—Full extension.

Ankle Joint and Foot.—The foot should be at a right angle to the leg and neither inverted (in varus) nor everted (in valgus), so that the tread comes naturally upon the heads of the first and fifth metatarsals. A slight degree of equinus, sufficient to allow for the height of the heel of the boot is not detrimental; severe equinus or any calcaneus is very disabling.

The above positions are those to be aimed at when ankylosis of the joint is expected; it does not follow that exactly the same positions are to be adopted when a return of mobility is looked for. In the latter case the position may be dictated by the nature of a co-existing fracture, or it may be adopted in order to retain a movement which may be difficult to secure later. For example, when return of pronation and supination is expected the fully supinated position of the forearm is almost invariably indicated because a return of full supination is often very difficult to secure. These

positions for splinting in contradistinction to the positions of ankylosis will be considered under the general principles of splinting.

When a joint is absolutely fixed it may be said to be fixed in a good position when its attitude approximates to the standard above described. When it diverges much from the standard the condition will be considered to be a malposition of the joint for which treatment is indicated. If a limited range of mobility remains, the position may be considered good if the standard position falls within this range, bad if the range falls short of the standard position. In the latter case treatment is indicated in order to correct this malposition, quite apart from any treatment which aims at securing a functional increase in the range of movement.

So that when a stiff joint has been classified into its proper pathological group, it is necessary further to note whether the position is good or bad, and still further to note whether there is any subluxation or dislocation, either traumatic or pathological. Having thus completed the diagnosis, it is then possible to decide upon a course of treatment; in doing so, however, it is as well first to form a general idea of the amount of functional use that will be eventually secured.

Prognosis of Stiff Joints.

1. A complete return of normal mobility and strength may be expected only in the simple functional cases and in cases of periarticular adhesions. If results of operative treatment are included, a similar perfect result may sometimes be obtained in the apparent limitation of movement due to the angular union of fractures, and in a few cases of limitation of movement by blocking by callus or by encircling bone. In the latter cases, however, the periarticular fibrosis and the sclerosis in the muscles will usually prevent full movement.

2. A return of a smaller range of useful movement may be expected in—

(*a*) Severe periarticular adhesions.

(*b*) Sclerosis of the capsule and muscles, and adhesions of the muscles to the synovial membrane and capsule.

(*c*) Cases in which there has been some interference with the joint surfaces by a fracture, also to a less extent in those in which there has been erosion of the joint surfaces by inflammation. In all these cases, however, there is a liability to a subsequent traumatic osteoarthritis which may render the movement painful and may cause the range of useful movement to become gradually less.

3. No return of useful mobility is to be expected (unless operative treatment is to be carried out) in—

(*a*) Severe capsular and muscular sclerosis.
(*b*) Considerable alteration in the joint surfaces.
(*c*) Intra-articular fibrous ankylosis.
(*d*) Bony ankylosis.

Treatment of Stiff Joints.

Nothing in surgery is more difficult than to lay down rules for the treatment of stiff joints. Not only must the probable pathology of the condition to be treated be estimated and the eventual result deduced from this, but also the idiosyncrasies of the individual joints must be borne in mind. For example, certain joints, such as the knee, as a rule, respond well to forced movements; others, such as the elbow, seem to resent such attempts, and improve only as the result of active use. Only the individual experience of the surgeon can enable the most rapid progress to be made. This is undoubtedly largely the result of the difficulty of reaching an accurate conclusion as to the pathological changes present in each case, and as to the extent to which limitation of movement is due to active inflammatory changes or to purely mechanical factors.

In the first place it must be realised that stiffness which results from active inflammation will not be improved, but rather rendered worse by the use of forced movements. The constant stretching of newly formed inflammatory tissue only stimulates further fibrosis, leaving an eventual increased stiffness. The proper treatment of stiff joints, in or around which inflammation is active, is rest, or, at the most, only such active movements as the patient can be induced to carry out himself.

Traumatic Myositis Ossificans.—Amongst the conditions which must be included as inflammatory is that in which new bone is formed in the muscles in the neighbourhood of an injured joint, usually classed as traumatic myositis ossificans. This condition most often follows a simple injury, such as a dislocation of the elbow or a simple strain of the knee. Pathologically it is probaby due to the periosteum being torn and osteoblasts from it being set free in the muscles. The clinical history of the condition as seen around the elbow is usually as follows. A simple dislocation of the elbow is reduced or a simple supra-condylar fracture in a child is set in a good position by flexion of the elbow. A month or more later attempts are made to get a return of full movement in the joint by massage and forced movements. To the annoyance of the surgeon and masseuse these

attempts do not improve this mobility, but rather lessen it. Perhaps then movement under an anæsthetic is tried; the result is that subsequently the range of movement diminishes still further until the joint becomes practically fixed. If an X-ray is taken in the early stages a faint bony shadow may be seen in front of the elbow joint, probably

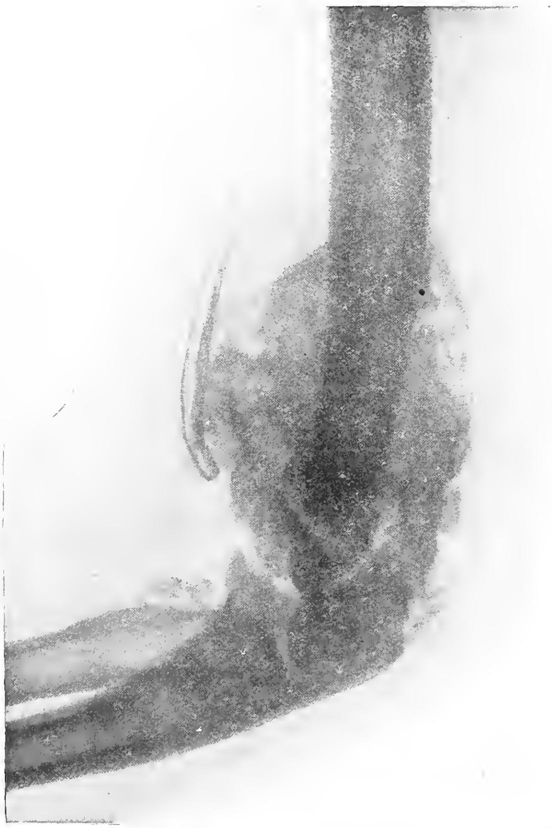

Fig. 33.—Myositis ossificans in the brachialis anticus muscle following a fracture of the lower end of the humerus which had been treated by vigorous massage. The new bone in the muscle and around the fracture abolished all movement.

in the brachialis anticus muscle; sometimes a similar shadow may be seen in the triceps. At this stage the movement that is most resisted and painful is that which stretches the affected muscle, so that if the shadow is in front of the joint it is extension that is most limited. The proper treatment is immediate and absolute rest to the joint from all movement in the standard position; this will result in a diminution in the inflammatory changes, the development of new

bone first ceasing and the bone formed then being absorbed. The period of rest required depends upon the stage at which the condition is recognised. If recognition is early and rest is adopted at a stage when the amount of new bone formed is slight and its organisation imperfect, a month's rest will often suffice; if, on the other hand, much and well-organised bone has already been formed, a much longer rest will be required to secure its absorption, and in very late cases rest may not in itself suffice and it may be necessary to excise the new bone. After the period of rest it is most important that no forced movement of the joint or massage should be carried out. The patient should be left to regain his full range of movement by light active use. If the bone has to be excised, this excision should be carried out at a late stage after prolonged rest, and the joint should again be rested after the excision, the return of mobility again being secured by active use.

Traumatic myositis ossificans may occur as the result of gunshot fractures as well as of all sorts of simple fractures, dislocations and strains of joints in military surgery. As already mentioned, it may also be found as the result of septic infection. It must be recognised by the X-ray appearances, but may often be suspected by the hard induration in the affected muscle which firmly resists any movement which stretches it.

Methods of Treatment of Stiff Joints.—The methods of treatment of stiff joints may briefly be stated thus—

1. Rest by immobilisation.

2. Mobilisation under an anæsthetic, the joint being put through its full range of movements and afterwards left free.

3. Mobilisation under an anæsthetic through a more limited range, the joint afterwards being left free.

4. Forced alteration of position of a joint, which is then immobilised in the new position.

5. Gradual alteration of position of the joint by the use of a splint or of a plaster-of-Paris appliance.

6. Operative procedures, which may be classified into—

(*a*) Division or lengthening of the tendons or muscles with division of adhesions.

(*b*) Division of the capsule of the joint.

(*c*) Excision of encircling bone or of callus or fragments which block movement.

(*d*) Osteotomy to correct position, either performed through the joint line or in its neighbourhood.

(*e*) Excision of the joint by the classical method.

(*f*) Arthroplasty, or the deliberate re-shaping of the bone ends

with the interposition of a flap of fascia or muscle or of a foreign substance, the object being to secure a new mobile but stable joint.

7. Methods of physiotherapy, *i. e.* by baths, massage, electrotherapy and gymnastic treatment.

Hyperthermal baths, particularly if the water is kept in movement, by increasing the vascularity, soften adhesions and render them more easily stretched by subsequent manipulation. Massage similarly softens resistant structures and also loosens them by the actual manipulations of the masseuse. Forced movement by externally applied manual force increases the range of movement, provided that it does not set up a reactionary inflammation. Electrotherapy scientifically applied, *i. e.* by direct stimulation of certain muscles or muscle groups, strengthens those muscles and thus increases the active movements in the direction in which they act. Gymnastic treatment acts in two ways: it can be used to force movements by applying the patient's weight or a part of it in the right direction; it can also be used to strengthen the action of certain muscles with a consequent increase in the range of movement in the direction in which these muscles work. Finally, treatment by ionisation, by diathermy, by X-rays and by radium have a certain effect in softening and causing the absorption of new fibrous tissue, and so may assist the increase of mobility.

In applying these methods to individual cases the following principles will serve as a useful guide—

1. Whenever inflammation in an active stage is present the joint is more likely eventually to become mobile if it is rested until the inflammation has ceased.

2. If full movement can be carried out immediately under an anæsthetic with so little tearing of adhesions that a subsequent inflammatory reaction is improbable, then this will be the quickest and best way of securing full return of mobility.

3. If forced movement is likely to produce an inflammatory reaction, then either gradual methods of physiotherapy must be used, or a small increase of movement only must be carried out under anæsthesia, or the position of the joint must be altered under anæsthesia and immobilisation in the new position carried out until time has elapsed sufficient to allow the inflammation to subside.

4. If movement is blocked by bone, or if there is any intra-articular fibrous ankylosis, or if there is dense sclerosis of the capsule or muscles or tendons or firm adhesions around the joint, then it is impossible to secure an increase of movement except by operative measures.

The actual treatment of a case of stiffness of a joint does not depend entirely upon the estimate of the pathological condition present and of the functional result expected. It must vary also according to the joint affected. Thus when the movement of the knee is limited by slight periarticular changes a single mobilisation under anæsthesia followed by massage and exercises will usually effect a cure. A similar treatment for an apparently similar condition around the elbow joint may, on the other hand, leave a greater stiffness than was present before treatment was commenced. For this reason the actual details of treatment, involving the application of the principles above described to the individual joints, must be left and considered for each joint in turn.

Finally, it must be remembered that in some cases a firmly fixed joint is more useful than a joint with a slight degree of mobility. This is particularly so when the slight movement is painful or when the joint tends to contract into a bad position. Such a fixed joint may be secured by the use of an external splint or by the operation of arthrodesis or by a limited excision. Fixation as a means of improving function is specially indicated in the shoulder and in the knee.

CHAPTER VI

FLAIL JOINTS

Joints in which movement is excessive and is not properly controlled by muscular action are specially frequent as the result of gunshot wounds. The reason for this is twofold. In the first place a comminution of the articular ends of the bones produced by the impact of a bullet or fragment of shell may itself cause much loss of bone. In the second place the actual or possible supervention of sepsis involving the dangerous complication of a septic arthritis has led surgeons to adopt the plan of removing considerable parts of the articular ends of the bones in these cases. In some cases the fragments of the bone are removed shortly after the wound has occurred, an excision of the wound with suture being performed and rapid healing resulting. In other cases the excision is performed at a later stage in order to enable the wound and the joint to be drained freely. In either case the procedure may result in a flail condition of the joint. It must be remembered that the pieces of bone removed will often include those that carry the attachment of important ligaments and muscles, and also that these wounds may be complicated by actual destruction or paralysis of muscles around the joint. Both these facts increase the liability of the joint to become flail.

No doubt in many cases this early excision of a badly shattered or septic joint has saved the limb or the life of a patient, and for this reason the procedure is not one that can be generally condemned. Surgeons who carry out early excision should, however, be made to understand how bad is the functional result of this operation, at any rate in a large proportion of cases, so that they may not perform it without due consideration, and may be induced to follow it up with an after treatment designed to obtain a stiff joint rather than a mobile one. There is still a prevalent idea that in the joints of the upper limb mobility is everything. Mobility of a joint without strength is useless, and a firm ankylosis in a good position is in every case preferable to a flail joint.

The action of a muscle is that of a force exerted upon one arm of

a lever. This can only be efficient if the lever has a fixed point or fulcrum; this fixed point being formed by the proper engagement of the ends of the bones at the joint. If the bone ends are so cut away that the fulcrum no longer exists, then the muscular action must become useless. When the head or the humerus, as far as the surgical neck, has been excised, the deltoid has no longer any power to abduct the arm until it has first lifted the stump of bone into apposition with the scapula. That is, it has first to bring the bone ends into apposition and so form a fulcrum; any remaining power that it possesses can then be exerted to abduct the arm. Excisions of the joints in the early stages, either primary for the removal of the comminuted fragments or secondary to secure drainage, must necessarily still be carried out in certain cases. We should endeavour to restrict this operation as far as possible and to carry it out in such a way and to follow it up with such after treatment as will prevent the production of a flail joint, aiming rather at the production of a fixed joint or of one with only limited mobility.

The Prevention of Flail Joints.

If the principles explained above are accepted the rules to be adopted in excising a joint are comparatively simple.[1]

1. In carrying out the excision the amount of bone removed should be only sufficient to serve the immediate end in view, *i. e.* removal of sufficient to render the wound clean and enable suture to be carried out in early cases, of sufficient to secure drainage in cases of septic infection.

2. Portions of bone which bear import ligaments and muscular attachments should be respected, and should be left if possible.

3. Sufficient bone should be left to enable the articular ends to engage with each other.

4. The limb segments should only be kept separated by extension for as long as is necessary to secure adequate drainage. As soon as possible the ends of the bone should be brought into contact by splinting and kept in contact.

5. The limb should be held after excision in the standard position. If ankylosis is expected the position should be the standard one for a fixed joint. If ankylosis is not expected the position should be the standard one for splinting.

Shoulder Joint.—Firm ankylosis of the shoulder in a good position

[1] It is hardly necessary to say that these rules are only intended to apply to early excisions and excisions for sepsis. Late excisions and arthroplasties are carried out with the definite idea of mobilising or of fixing the joint, and are governed by rules of their own.

gives a far better functional use than does a mobile joint after excision. It is even doubtful at present whether an arthroplasty of this joint to secure mobility at a late stage is advisable. Therefore all excisions of the shoulder should be as limited in extent as possible. In particular the tuberosities should be retained, as the muscular attachments to them are most important. The weight of the arm in the dependent position tends to separate the bones and increases the liability to the production of a flail joint.

Fig. 34.—Flail elbow resulting from the early removal of comminuted fragments of the humerus and olecranon. There was no power of active movement whatever.

After excision the arm should be abducted to a right angle and held there. This position serves two purposes, it relieves the tension upon the structures around the joint and thus prevents the distraction of the bone surfaces, and it also prevents overstretching of the deltoid and enables this muscle to preserve its function. The position of abduction is also an excellent one for the drainage of the joint, and prevents the tracking of pus down to the elbow region that is so often troublesome when the arm is left hanging. If it is found that the joint is stiffening and is likely to become fixed it should

be brought into the position of 60° abduction with slight forward flexion, recommended as the best for ankylosis.

Elbow Joint.—The elbow joint is one in which a flail condition is particularly frequent. Several causes contribute to this. In the first place it is a difficult joint to drain, in the second place there is a common misconception that a mobile elbow is essential and that ankylosis is a serious disability, and finally in the dependent position the forearm bones tend to be distracted greatly from the humerus.

Here again the excision should be as limited as possible. In the humerus every endeavour should be made to preserve the width of the condyles and the muscular attachments to them and to the supra-condylar ridges. Some part of the olecranon should be preserved, or, if this is impossible in a primary excision, the triceps should be re-attached to the ulna. There can be no doubt that wide excisions of the elbow are often performed with the idea of preserving mobility. It cannot be too often stated that the important point is to preserve stability by retaining as much of the shape of the bones as will enable them subsequently to engage. If ankylosis results and a mobile joint is wanted it can be secured at a later stage by arthroplasty.

In the after treatment the elbow should be kept at a right angle and the forearm supported. Wilson's arm splint is efficient for this purpose. A completely flail arm with functional inactivity of the flexors is very rarely seen when the elbow has been kept flexed. It is common when the arm has been left dependent.

Radio-Ulnar Joints.—Excision of the head of the radius, limited to the portion above the tuberosity, does not leave a bad functional result. The forearm should be kept supinated afterwards and active movements encouraged as early as possible. When both forearm bones are fractured high up, excision of the head of the radius in the early stages is inadvisable except in cases of urgent necessity, for it cannot remove all comminuted bone unless a portion of the ulna is excised at the same time (a procedure liable to be followed by a flail elbow joint), and if the radius only is excised a synostosis between the two bones is likely to occur.

Wrist Joint.—Excision of the lower end of the radius leaves a functional disability that is so serious that the operation should never be performed except as an alternative to amputation. Excision of the lower end of the ulna is less serious. Excision of individual carpal bones, or even of the major part of the carpus, is often advisable and leaves a very useful hand provided that the tendons are not too seriously injured and that the after treatment is well carried out. The trapezium and the joint between it and the first metacarpal

should be preserved at all costs, and the pisiform should also be preserved. If possible, a portion of the distal row of metacarpals should be left, so that the inter-metacarpal joints remain. The play between the individual metacarpal bones at these joints is most important to the function of the hand. In general the first row of carpal bones may be sacrificed freely, the second row less freely, the trapezium and the pisiform should be preserved.

The wrist should be retained afterwards in a position of extension at 45°. This can be carried out on a cock-up splint with the fingers extended to a hoop. In this joint mobility may be aimed at, provided that the wrist is kept extended.

Hip Joint.—Flail condition of the hip joint is comparatively rare. It is so obviously disabling that it is reserved by all surgeons as a device to save the limb or the patient's life. When excision is essential to secure drainage as little as possible should be excised. The neck of the femur and the trochanters should be saved, if possible, and only such extension should be kept up as will allow proper drainage to be effected and will prevent dislocation of the stump of the femur. Fixation should be secured on an abduction frame or on a net bed with the limb well abducted. The abducted position helps to prevent dislocation, and is also the best one for ankylosis in those cases in which bone has been lost and shortening is inevitable.

Knee Joint.—A flail knee joint is functionally useless without external support. Therefore all excisions of this joint should be as limited as possible and a subsequent bony ankylosis should be the object. Extension should only be kept up long enough to secure drainage whilst the acute septic stage passes off. After this the bones should be allowed to come together in the extended position and securely fixed by splinting or by the application of plaster of Paris.

Ankle Joint.—A flail condition of this joint is practically unknown; presumably in cases in which excision is indicated, either because of the comminution of the bones or because of sepsis, amputation is carried out as a routine.

The Treatment of Flail Joints.

When a flail condition of a joint has resulted from loss of bone and perhaps from associated injuries to the muscles, ligaments and nerves, the object of treatment must be to restore stability by surgical or by mechanical means. The ideal would be the reconstruction of the joint ends and the restoration of damaged muscles and ligaments. From the nature of things this can very rarely, if ever, be

possible; we have usually to be satisfied with a much less perfect result, either securing a mobile joint with a moderate degree of stability and strength, or else fixing the joint completely and thus restoring the utility of the rest of the limb.

FIG. 35.—Flail elbow with extensive scar, the central part of which remained permanently ulcerated. The ulnar nerve was paralysed. Treated by excision of the entire scar with immediate suture, primary union resulted. The ulnar nerve was explored at the same time and was continuous. Faradic stimulation of the nerve caused contraction of all the ulna intrinsics in the hand.

Fixation of the joint is nearly always the easiest method of treatment, and is very often the most satisfactory; for in all the large joints firm fixation results in better use than does mobility with weakness. Fixation of the joint may be secured, either by a surgical procedure which aims at the production of a bony ankylosis (arthrodesis) or by applying an external splint which encloses the joint and prevents movement. The production of a bony ankylosis is a comparatively simple matter in a joint in which the articular ends of the bone are intact. It may, however, be extremely difficult in these cases of flail joint in which the articular ends of the bone are lost and in which, in addition, the remaining ends of the shafts of the long bones are perhaps rarefied and terminate in a narrow point. The mere approximation of the ends of the bone after refreshing them will seldom be sufficient to secure bony ankylosis, except in the case of the knee joint. In the shoulder the acromion can be brought in as a lateral splint to assist in fixation. In the elbow a bone graft or bone peg will be required, and in the wrist the best chance of obtaining bony union is by driving the ends of the radius and ulna into the cancellous bone of the carpus. The surgery of these conditions is extremely difficult and is still in the stage of experiment; failures to secure union are frequent.

The best form of permanent external splint is a moulded leather case, made by blocking leather upon a plaster-of-Paris cast taken whilst the joint is held in the position in which fixation is desired: this position will, of course, be the standard position for fixation of the particular joint.

Restoration of a mobile joint may be attempted by various methods, of which the following are examples.

1. If the loss of bone is not very great and the muscles around the joint are, for the most part, intact, it may be possible by prolonged splinting to hold the bone surfaces in contact, and to enable the muscles to undergo an adaptive shortening and thus to regain control over the joint. For example, when the head only of the humerus is lost, prolonged fixation in the abducted position may enable the deltoid muscle to regain power of elevating the shoulder; the arm may then again become useful for light work; it is, however, certain to remain weak. In a similar way in many cases of flail condition of the elbow, prolonged fixation in the flexed position will restore the power of the biceps to flex the joint. Lateral mobility, however, will remain, and if the triceps attachment is missing, as it so often is, power of active extension will not return.

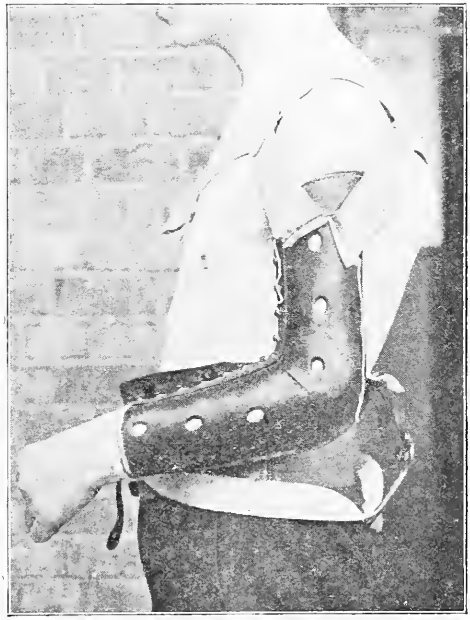

Fig. 36.—Moulded leather splint applied to the case shown in Fig. 35 after the operation.

2. In some cases in a joint in which efficient but weak movement has thus been restored, additional security can be given by the use of a supporting appliance. In the elbow lateral mobility can be stopped by fitting moulded leather arm and forearm pieces with steel hinge joints at the elbow; by adding a stop which limits extension to 110° the biceps can be supported and enabled to carry out its work more efficiently. Such an appliance tends to slip down the arm; the only good method of preventing this is by moulding the leather arm-case and the lateral steels in over the supra condylar ridges of the humerus. Unfortunately, in many cases of flail elbow these ridges are lost; the support then tends to slip downwards so that the steel joints do not remain correctly centred and flexion of the elbow becomes difficult or impossible. In such cases complete fixation in a solid leather case is preferable. A flail but mobile hip

joint can be supported by the use of a Thomas Caliper splint which carries the weight direct from the pelvis to the ground and thus prevents the stump of the femur from slipping up on to the dorsum ilii.

3. It may occasionally be desirable to attempt to restore the use of muscles by re-attaching them or by shortening them, or to transplant muscles to replace the action of some that are lost. For example, the clavicular part of the pectoralis major may be transplanted to replace the deltoid for a flail condition of the shoulder in which there has been little loss of bone, but in which the deltoid is destroyed.

FIG. 37.—Movement photograph (double exposure) of the case shown in Figs. 35 and 36 showing the range of active flexion resulting from the wearing of the splint for two months. There was no active extension, and lateral mobility remained, so that it was necessary to fit a support with steel joints at the elbow.

4. A further line of experimental work is that of bone transplantation which aims at the formation of new articular ends to the bones, so that these can engage properly with each other and thus form a fulcrum for the leverage action of the muscles. The upper end of the humerus has been replaced by the head and upper end of the fibula, a mobile shoulder joint resulting; and in the elbow attempts have been made to fix lateral grafts on the sides of the humerus between which the forearm bones can rest in a socket. In these cases grafts have been taken from the patient himself. Other attempts have been made to graft an entire joint from an amputated limb; this can very seldom be possible, and they introduce the principle of homoplastic grafting. We know from experience that grafts taken from another individual are much less likely to survive than are those taken from the patient himself. No doubt many other experiments will be done in the grafting of bone for these flail conditions of joints. On the whole, the reconstruction

of a joint by the use of bone grafts taken from the patient himself seems to be the most likely to succeed; when this is impossible, and when functional utility cannot be restored by the treatment of the muscles alone, the best surgical procedure is undoubtedly the attempt to produce a bony ankylosis.

CHAPTER VII

INJURIES OF THE NERVES. PATHOLOGY AND DIAGNOSIS

Pathological Anatomy.

Injuries of the nerves in war wounds may result from actual damage to the nerves by the missile, or from contusion or crushing, or from pressure upon the nerve of cicatricial tissue or of bone; hence we get the following varieties of nerve injury.

1. *Simple Contusion.*—There is hæmorrhage into the sheath of the nerve, the axons themselves being undamaged and uninterrupted.

2. *Crushing.*—In addition to the hæmorrhage into the nerve, some of the axons are actually divided.

3. *Perforation.*—The missile has passed through the nerve, dividing some part of it and interrupting the axons of this part.

4. *Section.*—The whole nerve has been divided, the ends may be separated and scar tissue or other tissue interposed. In addition, a length of the nerve, amounting perhaps to several inches, may have been destroyed.

5. *Compression.*—The nerve was originally uninjured, but has become constricted by the pressure of scar tissue or of callus.

When the axons or some of them have been divided, their distal part beyond the lesion degenerates. The proximal end of the distal fragment enlarges, but the swelling thus formed consists only of new interstitial tissue and is a glioma. From the end of the proximal fragment new axis cylinders grow out. If the passage into the distal end is free these will enter it and grow down in it to their distribution in the periphery, the nerve thus regenerating. If, however, there is any obstruction to this growth—for example, an area of scar tissue, or perhaps some other interposed tissue—these axis cylinders will curl back in the scar tissue and will form a swelling which constitutes a neuroma. Even when apposition of the ends of the nerve is almost perfect and when there is no intervening scar tissue, as in a successful suture, a certain proportion of the axis cylinders will fail to enter the distal end and will curl back, a neuroma thus being formed. In addition, they often penetrate the surrounding tissue, so that they may be found in a microscopic section of the adhesions around the nerve.

When the axons have not been divided, but the nerve has simply been contused and hæmorrhage has occurred into it, a subsequent organisation and fibrosis in the interstitial tissue of the nerve will occur, varying in extent with the severity of the damage. This may result in the production of a swelling, which is, however, not usually very large. In this case the axons only undergo alteration at a late stage, and then only in cases in which the fibrosis is considerable. In such cases the changes are those due to compression of the axons by new fibrous tissue and do not constitute a complete interruption.

These are the typical changes of a complete division and of a pure contusion, but every case is not so simple. We may find division of only half a nerve, a neuroma and glioma form on the extremities of the cut half, the intact part of the nerve running alongside these two swellings; or with such a section of half a nerve, the other half may be contused. In other cases, particularly in large nerves, perforation of the nerve may divide some of the central fibres, so that a central neuroma forms, or when the nerve is crushed some of the fibres may be divided, others being left intact; a neuroma thus forms which is incomplete, inasmuch as some of the fibres are continuous through it.

Examination of a Nerve Injury.

The recognition of complete division of one of the important nerves is a simple matter, yet many cases of nerve injury still escape diagnosis. It is of the utmost importance that every complete lesion of a nerve should be recognised at the earliest possible moment. The diagnosis of incomplete lesions and of irritative lesions of the nerves is a most difficult matter. In these latter cases the assistance of an experienced neurologist is essential, but every surgeon who occupies himself with nerve surgery should be prepared to diagnose simple complete division of the major nerves himself.

The points to be noted are as follows:—

1. *The Track of the Projectile,* bearing in mind the position in which the limb was at the moment of being struck; from this the nerves likely to have been injured may be recognised.

2. *The Complete Loss of Voluntary Movement in the Muscles supplied by the Nerve.*—The least flicker of voluntary power in a muscle implies a continuity of its nerve. In investigating voluntary movement care must be exercised on two points. In the first place the muscles may be able to carry out a movement, but only if placed under the most favourable circumstances. For example, in an apparent paralysis of the extensors of the wrist these muscles may

be powerless to raise the weight of the hand, but if the forearm is held pronated so that the palm is vertical, the extensors may be able to bring the hand backwards. In the second place, it is often possible for the patient to carry out a movement indicated by the use of other muscles, sometimes actually by the muscles which are opponents of that which is being tested. The best example of this is in paralysis of the extensors of the thumb. When these are completely paralysed the patient can extend the metacarpo-phalangeal and interphalangeal joints of the thumb by flexing the wrist and at the same time carrying the hand to the ulnar side; this movement causes tension of the long and short extensors of the thumb, and so brings about extension. In testing for voluntary power in individual muscles in the forearm, all joints except that the movement of which is being watched should be held firmly by the surgeon himself. In no branch of surgery is an exact knowledge of anatomy so essential as in the diagnosis of nerve injuries; the surgeon must not only know the exact attachments and nerve supply of the muscles, but he must also have an accurate conception of the exact action of each muscle upon each limb segment.

3. *The Presence of an Area of Anæsthesia.*—It is necessary to examine for this by a routine method. The use of rough-and-ready methods in which deep sensibility is confused with sensibility to light touch is responsible for many errors. Sensation for light touch should be tested with a piece of cotton wool, starting from the periphery and working longitudinally in straight lines up the limb, then starting laterally and working circumferentially around the limb; an area of insensibility to light touch can thus be marked out. Then a similar test is carried out with a sharp pin, pricking lightly, and explaining to the patient that he is to recognise only sensation of a prick, ignoring a mere touch. In this way an area of insensibility to prick is marked out. For practical purposes these two tests are sufficient; more elaborate investigation of the loss of sensation of deep pressure, of heat and cold and the sense of position, etc., may be valuable in special cases. For a consideration of the methods of testing and of the significance of all varieties of sensory loss, works on neurology must be consulted.

Apart from errors in the method of testing, mistakes arise chiefly because the surgeon expects to find too large an area of insensibility. Thus in injury of the median nerve, the area of complete anæsthesia to light touch often includes only the palmar surface of the index finger and a small area of the palm at its root. The full anatomical distribution of the nerve includes the whole palmar surface of the thumb, index and middle fingers, the radial side of the ring finger,

the corresponding half of the palm and the dorsal surfaces of the two distal phalanges of the same fingers and of the last phalanx of the thumb. Over most of this area sensibility is diminished, but not lost; the recognition of the comparatively small area which is supplied exclusively by one nerve is of great practical importance.

4. *Alterations in the Electrical Reactions of the Muscles.*—For purposes of diagnosis the electrical tests may be reduced to great simplicity. First individual muscles should be tested with the faradic current; if they can be made to contract, it is certain that there is no complete interruption of their nerve supply. The only exception to this is in the case of a very recent injury, in which degeneration of the distal part of the nerve has not yet occurred. If the muscles do not respond to a faradic current, they should be tested with an interrupted galvanic current; contraction will always be obtained if any muscle fibres remain uninjured. The character of the contraction is important; when the nerve is intact, the contraction produced by an interrupted galvanic current is sharp and rapid; when the nerve is divided and the lower part has degenerated, the contraction is slower and more wave-like. This alteration in the character of the contraction is both more easily seen and more valuable than the alteration of polar reactions, which is usually expressed by saying that in degeneration of the nerve A.C.C.$>$K.C.C.

Finally, in cases of suspected pressure upon the nerve it is as well that the nerve trunk itself should be tested with a faradic current. Sometimes when the nerve is constricted and the muscles supplied by it fail to contract voluntarily but to react to a faradic current, stimulation of the nerve itself above the lesion fails to produce a contraction of the muscles; this shows that there is an interruption to the nerve sufficient to prevent stimuli from above reaching the muscles, but insufficient to cause a complete block that will interfere with the nutrition of the muscles. All these tests should be verified if there is any doubt, by comparison with the sound side.

For details of the methods of testing muscles as well as for discussion of more elaborate modes of investigation and of the meaning of alterations in electrical reactions works on neurology or on electro-diagnosis must be consulted. The facts expressed above are sufficient to enable the surgeon to appreciate the diagnosis of a complete or incomplete nerve lesion by simple electrical tests.

5. *Investigation of the Nerve at the Site of the Injury and throughout its Course.*—In the first place the nerve should be palpated in order that the neuroma upon it, if present, may be felt. Such a neuroma, particularly if pressure upon it causes tingling to be referred to the area of sensory distribution of the nerve, is an important indication

that the nerve trunk has been partly or completely divided at this spot, but much attention must not be paid to the presence of such a lump, for it is easy to mistake a cicatricial mass for a neuroma: moreover, all neuromata do not indicate complete division of the nerve; this test must be considered in conjunction with the other phenomena present.

Actual pain upon pressure over the nerve is important; some neuromata are painful, but any pain on pressure below the site of the injury is an indication that the nerve has not been completely divided, but is rather the seat of a neuritis.

Finally, the course of the nerve should be lightly percussed with the finger. When a nerve has been divided, but is regenerating, this percussion, by stimulating the young axis cylinders, causes a tingling sensation to be referred to the area of sensory distribution; this sensation, called "formication," is an important indication that the nerve is undergoing regeneration.

These five points on examination are the important ones. If methodically carried out, they should leave no complete lesion of an important nerve undiagnosed. A full investigation of a nerve injury, or suspected nerve injury, includes many other points, such as the examination of the reflexes, of the degree of atrophy of the muscles, of muscular tone and sensibility, of contractures, of alterations in the skin, hair and nails, and of the vascularity of the limb and trophic changes. Some of these will be referred to again in considering the differential diagnosis of nerve lesions and irritative lesions of the nerves.

Clinical Types of Nerve Lesions.

1. *Complete Interruption of a Nerve* (*i. e.* division of all the axis cylinders).

(*a*) The paralysis of voluntary movement in the muscles supplied by the nerve is immediate and complete and is accompanied by a loss of muscular tone and by progressive wasting.

(*b*) Anæsthesia to light touch is complete over the area which is exclusively supplied by the sensory fibres of the nerve.

(*c*) After an interval of about a week the muscles cease to respond to stimulation with the faradic current; later the response to galvanic stimulation alters until the classical R.D. is reached.

(*d*) After an interval a swelling appears upon the proximal end of the nerve at the point of interruption; pressure upon this is not painful, but when regeneration of the axis cylinders

has commenced pressure upon the neuroma produces formication referred to the area of sensory distribution. Pressure upon the line of the nerve below the lesion produces no pain and no formication.

(*e*) The area of sensory supply may be slightly cyanosed and œdematous. Ulcers may form as the result of unnoticed injuries, but trophic changes are not marked.

2. *Compression of the Nerve by Scar Tissue or Callus.*

(*a*) Paralysis of the muscles is more or less complete according to the degree of compression; there is less loss of tone and less wasting than in complete interruption.

(*b*) The extent of the sensory loss is very variable.

(*c*) Reaction of the muscles to a faradic current may remain, or this may be lost, but the galvanic response may remain normal in character, or in severe compression there may be true R.D. Stimulation of the nerve above the point of compression may produce no movement, although the reactions of the muscles themselves are normal.

(*d*) There is no pain on pressure at the site of the lesion and no pain or formication on pressure upon the nerve at a lower level.

(*e*) Cyanosis, œdema and trophic changes are absent.

3. *Irritation of the Nerve.*

(*a*) The muscles supplied by the nerve are not paralysed, or are only partially paralysed; often these muscles show little or no voluntary action, but are in a condition of slight tonic spasm. In severe cases this may pass on into a condition of contracture, with interstitial fibrosis of the muscles. Thus the muscles show a series of changes, from the slight spasm of a painful neuritis, through the fixed deformity of an old neuritis, to the rigid woody muscles seen in some cases of causalgia.

(*b*) There is no anæsthesia; instead there may be hyperæsthesia, or else the perception of all classes of sensation as pain.

(*c*) The muscles either retain their response to faradic stimulation, or else react normally to galvanic stimulation. There is no R.D.

(*d*) Pain at the site of the lesion, along the course of the nerve below, and in the muscles supplied is invariable. Formication is absent—at least, until the pain is disappearing.

(*e*) Trophic changes are pronounced; there may be cyanosis,

> œdema, excessive growth of hair, loss of normal corrugation of the skin, obvious desquamation of the skin, and furrowing and cracking of the nails. The part may sweat profusely, or, on the other hand, may be excessively dry. In severe cases the muscles become fibrotic, the tendons adherent, and the joints fixed by periarticular adhesions. The bones as shown in X-rays are extremely rarefied.

There are a number of different types of irritative lesions of the nerves; the following three are the chief, but it does not follow that every case can be strictly classified as falling into one of these three groups.

1. *A Slight Neuritis.*—The nerve is tender at the level of the injury, and the muscles supplied by it show a slight persistent spasm; trophic changes are not marked.

2. *A More Severe Neuritis.*—There is great pain in the nerve, more muscular spasm, and very pronounced trophic changes.

3. *Causalgia.*—This is a condition of intense and persistent neuralgia, which was first described by Weir Mitchell during the American War of Secession. The pain is referred to the area of sensory distribution of the nerve, is very persistent, and is greatly aggravated by any movement. The limb is often kept completely immobilised by the patient, who may also wrap it up in cotton-wool to protect it from alterations of temperature and from contact with anything in the least hard. The facial expression usually demonstrates the severity of the pain, and every movement may be guarded and slow, so as to avoid the least jarring of the injured limb. Trophic changes are very marked. In causalgia of the median and ulnar nerves there is often much wasting of the skin and subcutaneous tissues on the palmar surface of the last phalanges of the fingers; associated with this there is very rapid growth of the nails, with the result that the skin extends on the under-surface of the nail in such a way as to make it impossible to cut the nails without causing bleeding.

4. *Regeneration of the Nerve.*

(*a*) When a nerve has been interrupted and recovery is taking place either spontaneously or after suture, the investigation of the line of the nerve trunk by percussion will demonstrate the presence of formication—that is, of tingling referred to the area of sensory distribution; this sensation is due to the stimulation of young sensory axis cylinders, the level to which it is felt demonstrates the level to which these new axis cylinders have extended; therefore, when a nerve

is regenerating formication should be found to extend further and further down the limb as recovery proceeds.

(*b*) Voluntary power returns in the muscles, preceded by the return of tone in these muscles. As the nerve regenerates from above, those muscles which it reaches first recover first. For example, in the musculo-spiral nerve the supinator longus, extensor carpi radialis longior, extensor carpi radialis brevior, and extensor communis, recover in this order; later this recovery is followed by that of the extensors of the thumb and of the index finger.

(*c*) The response of these muscles to galvanic stimulation becomes brisker, and then excitability to faradic stimulation returns. It is generally considered that voluntary power returns before faradic excitability; it seems doubtful if this is actually so. In larger muscles—for example, the extensor carpi radialis longior—whose action is not particularly complex, voluntary contraction is usually seen before any response to faradic stimulus can be obtained. On the other hand, in the case of small muscles with fine movements—for example, the interossei—faradic response is often present long before any voluntary action can be demonstrated; probably by using a suitable fine wire coil, faradic response can always be demonstrated before voluntary power returns.

(*d*) Sensation returns gradually by the slow narrowing of the zone of anæsthesia.

(*e*) Trophic changes disappear. After simple division of the nerve these changes disappear comparatively early. In irritative lesions they disappear only very slowly.

Note on Regeneration of Nerves.—In the process of regeneration of a nerve every axis cylinder grows out individually from the central end, penetrates the distal part of the nerve, and grows along this until it reaches the end organ in the muscle, skin, or other part. When a nerve supplying a single muscle is divided and sutured the process is simple; the axis cylinders return to the muscle which they originally supplied, although they may not actually reach the same muscle fibres that they supplied in the past; their function is unaltered, and very little re-education is required to enable impulses from the central nervous system to produce the desired movements. Practically as soon as the axis cylinders have completed their regeneration voluntary power returns, and only use of the muscle is required to bring it back almost or quite to its original power.

When a nerve which is chiefly motor in function, such as the

musculo-spiral nerve, is sutured, the process of regeneration is a little more complex, but still comparatively simple. The axis cylinders may or may not reach the muscles that they formerly supplied—for example, a group of axis cylinders which were originally destined for the extensor carpi radialis longior, may, instead of reaching that muscle, find their way to the extensor communis digitorum; this does not mean that these fibres are wasted, but simply that a fresh co-ordinating mechanism in the central nervous system has to be re-educated. In the case of the musculo-spiral nerve all the muscles supplied belong to one group, their functional use is comparatively simple, and, consequently, this central re-education of co-ordination becomes a simple matter, and voluntary power and voluntary control return soon after the completion of the regeneration of the axis cylinders.

If the muscles supplied by the nerve vary more in action and if their movements are finer, then the fact that individual axis cylinders may reach a muscle other than that which they formerly supplied is of more importance, because it must necessitate a more complex re-education of the centres. This is the case in the intrinsic muscles in the hand supplied by the ulnar nerve, and it is probably for this reason that the return of voluntary power in the ulnar intrinsics is slow, and is definitely preceded by the return of response to faradic stimulation.

Actually the re-education after regeneration of a nerve is still more complex, because voluntary control of muscles depends not only upon the regeneration of the motor fibres of the nerve, but also upon the restoration of sensory fibres, including those which supply the muscles and the tendons. These, again, during their regeneration may take a wrong course, necessitating additional central re-education.

When a nerve which is half muscular and half sensory is sutured, there must be a considerable chance of motor fibres taking a course to a sensory distribution, and of sensory fibres passing to a motor distribution; presumably these fibres are wasted. This consideration serves as an explanation of the fact that nerves which are largely motor, such as the musculo-spiral, recover more rapidly and more completely after suture, than do those which are largely sensory, such as the median.

Another consideration affects such nerves as the median, the sensory distribution of which covers an area over which perceptions are accurate and fine. We judge of the recovery of sensation by the appreciation of touch, but the axis cylinders which reach a particular area of skin after regeneration are not necessarily those which formerly supplied this area; therefore, the central perceptive

centres must be re-educated before these new sensations of touch can be referred to their true locality. Obviously this must take time, and it will also be evident that in parts over which sensation is comparatively rough, such as the leg and foot, this re-education will be simple and quick when comparison is made with areas over which sensation is fine, such as the distal parts of the fingers. Hence we find that a full return of sensation after suture of the median nerve only occurs after a long interval, amounting even to two or three years.

5. *Mixed Lesions of Nerves.*—It does not follow that every lesion of a nerve must consist of a pure interruption, or of a simple compression, or, in fact, of any pure lesion. It is not uncommon to find symptoms of interruption of part of the nerve and irritation of the rest, or of compression of a nerve, with interruption of certain fibres or bundles; in this case the clinical picture is naturally most complex, but an analysis of the signs will usually lead to a correct diagnosis. The most important point for decision is the diagnosis between partial interruption of a nerve and interruption or compression of a nerve which is recovering; if the former condition is present, the nerve should be explored forthwith; if the latter, treatment should be by other accessory methods.

The points which will assist the diagnosis are—

(*a*) The progressive recovery in the muscles supplied from above downwards; that is, in the order which the nerve supply reaches them. If, for example, in a lesion of the musculo-spiral nerve in the middle of the arm, the spinator longus and extensor carpi radialis longior are active, but the muscles below are still completely paralysed, it may be as well to wait and see if the muscles next in order (extensor carpi radialis brevior and extensor communis) recover; if they do, then the nerve is clearly regenerating; if they do not, then there must be a partial interruption. On the other hand, if the supinator longus and extensor carpi radialis longior are paralysed, but some of the muscles lower down—for example, the extensors of the thumb—are still intact, we may be sure that there has been a partial interruption of the nerve.

(*b*) The presence of formication upon percussion over the nerve below the lesion is an important indication that regeneration is proceeding, and that the partial extent of the paralysis is due to this and not to an interruption of a portion only of the nerve.

General Diagnosis of Nerve Injuries.

We may distinguish three conditions under which diagnosis of an injury to a nerve may have to be carried out in military surgery. First, the discovery of the existence of an interruption to a nerve in a recent wound. Secondly, the diagnosis of the presence of interruption, compression, or irritation of a nerve in a wound at a later stage after healing or partial healing having occurred; and, thirdly, the diagnosis of the presence of an organic lesion of a nerve in a case which shows additional symptoms of paralysis or anæsthesia which are certainly functional in their origin.

The early discovery of the presence of signs of interruption of one of the important nerves, soon after the wound is sustained, is very important as an assistance in the diagnosis of the exact nature of the nerve injury at a later date. This early diagnosis can usually be completed very rapidly by using certain test movements, watching to see whether these are possible through even a very slight range, and rapidly testing for anæsthesia to light touch over particular regions. For example, when there has been a perforating wound through the middle of the arm, the patient is made to extend his wrist as a test for the musculo-spiral nerve, to flex his wrist, and to flex the last joint of the thumb and index finger as a test for the median nerve, and to spread his fingers as a test for the ulnar nerve. The sensation on the palmar surface of the tip of the index finger and of the little finger should then be examined with cotton wool. In this way any complete interruption of the three important nerves supplying the forearm and hand can be discovered in a very few minutes. As a rule, a more complete examination will be left until a rather later stage.

The diagnosis of the presence of a nerve lesion and of its nature at a later stage, after the wounds have healed, requires no comment, except in so far as it is liable to be complicated by the existence of a functional element as an addition to the organic paralysis. The chief safeguards against the diagnosis of a functional paralysis as organic, or, on the other hand, of an organic paralysis with functional additions as purely functional, consists in a careful examination of the exact line of the wound and of the course of the nerve from this point down the limb, and in a careful consideration of the distribution of the paralysis and anæsthesia, and the comparison of these with the anatomical distribution of the nerve.

The chief difficulty occurs in those cases in which there is an actual injury to a nerve with a considerable functional addition to the symptoms; of this type the following are examples :—

I. Interruption of a nerve with complete paralysis of the muscles supplied by it, and anæsthesia over the area of its sensory distribution, with in addition a wider area of anæsthesia of a functional type and a paralysis of muscles supplied by some other nerve. Thus a man wounded in the middle of the forearm had complete anæsthesia of the hand, limited above by a circular line around the wrist, and also paralysis of all the extensor muscles of the wrist and fingers. Careful examination showed that in addition to the undoubtedly functional addition, he had a complete interruption of the median nerve at the site of the wound.

II. There may be interruption of a nerve with complete paralysis and anæsthesia, and in addition a functional disuse of other muscles supplied by the nerve at a higher level. For example, in a case of paralysis of the posterior interosseous nerve below the elbow, the supinator longus and extensor carpi radialis longior may be functionally inactive, although they are not truly paralysed and have normal electrical reactions. It is not very rare in an injury to the median nerve at the middle of the forearm to find that the index finger and thumb cannot be flexed, but the muscles which carry out these movements get their nerve supply from the median nerve at a higher level; the muscles, in fact, are intact and not paralysed, but the anæsthesia of the thumb and index finger has probably induced the patient to think that he is unable to carry out these movements.

III. In some cases of slight irritation of the nerve there is spasm of the muscles supplied by the nerve and a functional paralysis of the opposing muscles. For example, in irritation of the median nerve above the elbow all the flexor muscles of the fore-arm may be in a condition of slight tonic spasm, and this may be associated with complete wrist drop due to a functional paralysis of the extensor muscles.

CHAPTER VIII

SURGICAL TREATMENT OF NERVE INJURIES

Indications for Operation.

Whilst operation upon an injured nerve should be postponed until the diagnosis is as complete as possible, it should not be postponed indefinitely, but in cases in which it is indicated should be carried out as early as possible. The exploration of a nerve by a competent surgeon whose knowledge of anatomy is good and who is a capable dissector involves practically no risk. As a rule it would be better that a nerve should be explored unnecessarily rather than that the patient should waste several months waiting for regeneration which cannot take place. The cases which require surgical intervention are the following :—

1. All cases of complete interruption of a nerve; the only exception to this is that in the early stages, particularly where there has been a clean perforating wound by a bullet accompanied by much extravasation of blood, it is not uncommon to find a complete paralysis of a nerve, which clears up in the course of a few weeks, or perhaps in a month or two. These cases are probably physiological interruptions of the nerve by hæmorrhage into the sheath. Practically no one is likely to wish to explore these nerves before the initial bruising of the tissues has disappeared, and by the time this has occurred in most cases recovery will be commencing.

2. Cases of incomplete interruption of a nerve which have been watched carefully for a period of weeks and which show no signs of improvement, particularly if a bulb can be felt at the point of interruption and if the symptoms and signs point to a lesion of a definite portion of the trunk of the nerve.

3. All cases of compression of a nerve.

4. Irritative lesions of a nerve, if a painful bulb is present, if there is an accompanying paralysis, and if pain is very severe.

Finally, it may be said that when a case of nerve injury has been watched for some weeks or months, and when there is no sign of regeneration, if the surgeon feels in any doubt as to the advisability of exploring, he will probably be right if he decides to explore

forthwith. Provided that he dissects carefully, examines the nerve by palpation and by testing electrically on the table before interfering with it to suture it, he can do no harm; and by deciding on intervention without further delay, he will save time and improve the chance of recovery if the nerve proves to have been interrupted.

Technique of the Operation for Exploration of a Nerve.

Operation upon a nerve for the effects of a gunshot wound takes the form of exploration of a nerve and subsequent treatment of the nerve trunk either by (1) liberation from scar tissue, or (2) excision of the ends and suture, or (3) nerve grafting; which of these methods is applicable can often only be finally settled in the course of the operation.

Incision.—The incision should be along the course of the nerve, and should extend up and down to levels at which the nerve is presumably healthy and normally situated; any adherent scar in the line of the incision should be excised, if this is possible. The skin edges are immediately undercut sufficiently to allow of easy dissection, and strips of sterilised linen are attached to the skin margins by means of tissue forceps.

Exposure of Nerve.—The nerve should first be looked for well above the level of the injury, where its relations are normal and where it can consequently be easily found by using anatomical landmarks. It can then be traced down to the level of the injury by careful dissection. Where there is no scarring much of this dissection can be carried out bluntly; where scarring is present the knife must be used. Next, the nerve must again be found below the injury where its relations have again become normal; from this point it can be traced up to the site of the injury. During the dissection the level of origin of important branches must be remembered, and great care must be taken not to damage them. No branches ought to suffer injury during the operation; only if branches are given off at the actual level at which the nerve has been damaged ought there to be any question of permanent loss. If a muscle which crosses the nerve impedes the dissection, it must be divided if necessary; whenever possible, however, the muscular fibres should be split longitudinally instead. If it is necessary to divide a muscle, it is better to do so close to its insertion and to turn it back, as in this way the nerve supply of the muscle can usually be preserved. For example, in exploring the sciatic nerve in the gluteal region, it may be possible to get sufficient exposure by splitting the fibres of the gluteus maximus longitudinally; if not, the muscle should be split and the lower part divided close to its insertion and turned

upwards and inwards. In exploring the median nerve in the middle of the forearm, it is often necessary to divide the pronator radii teres near its insertion and to turn it inwards.

The upper end of the nerve may be found to enter dense scar tissue, or it may lie comparatively free and end in an obvious bulb. In the former case, the scar tissue must be split longitudinally and the nerve thus traced. If the nerve lies under callus, or a bony bridge, it must again be traced by carefully chipping away the bone. Often at this stage there will be doubt as to whether there is a complete interruption of the nerve, or a partial interruption, or no interruption at all. The same doubt arises when the upper end of the nerve terminates in a bulb from which the lower end immediately emerges. In all such cases, no matter what opinion has been arrived at by preliminary investigation, the nerve should be tested electrically at the time of the operation, and in cases in which the nerve is compressed by scar tissue, or by callus, this testing should be repeated after the nerve has been completely freed.

Testing the Nerve Electrically.—The nerve should be tested by stimulation with a faradic current of low intensity. One electrode is applied by a pad to any part of the body; the other pole is attached by a sterilised wire to a probe-pointed electrode which can be applied directly to the nerve. The nerve should be raised on a glass rod and the surrounding part dried as thoroughly as possible. The distal part of the limb must be uncovered. The nerve is then stimulated with a faradic current, interrupted by a metronome, the current being at first very small and being gradually increased. Care must be taken not to produce contractions of other groups of muscles, particularly of the opposing muscles, by a spread of the current. It is quite easy to mistake the movements produced by the contraction of opposing muscles for small movements of the muscles that are being watched. As the result of this test it may be found (*a*) that the muscles supplied by the nerve do not respond at all, indicating that there is a complete interruption of the nerve, and therefore probably a necessity for suture; (*b*) that certain muscles can be made to contract and not others: this indicates either interruption of a part of the nerve or that the nerve has been interrupted and is regenerating. The decision between these conditions must be made by considering which muscles react and what is the condition of the nerve as demonstrated by dissection; (*c*) that the muscles all contract, indicating that there is continuity in the nerve and that excision and suture is not indicated, unless the operation is being carried out for the relief of pain.

When a part of the nerve is interrupted a careful dissection will probably enable the operator to divide the nerve trunk into two parts, one of which is continuous, the other ending in a bulb. If this can be done, the nerve should be split, the continuous part left and the other part treated by excision of the ends and suture.

Suture of the Nerve.—In cases of complete interruption with a bulb (neuroma) on the proximal end and a second swelling (glioma) on the distal end, the two ends should first be completely freed to points at which the nerve is quite healthy and is situated in normal tissue. The swellings should be seized with Kocher's forceps and gentle traction made. If there is no considerable loss of substance it will be possible to make the ends overlap; if this cannot be done, a blunt dissector should be passed upwards and downwards around the nerve, in order to free it more completely. Additional traction should be made and the neighbouring joint flexed, so that the ends proximate more easily. When it is evident that regions of the nerve that are apparently healthy can be brought into apposition the suture may be proceeded with.

The upper end of the nerve is first cut across with a fresh sharp knife and the cut surface examined; it should show healthy nerve bundles surrounded by perineurium and without any excessive interstitial fibrous tissue. The lower end is similarly treated; it also should show nerve bundles of smaller size, again not imbedded in excessive fibrous tissue. If at either end the nerve bundles do not appear normal, or if there is much scar tissue in the nerve, more must be cut away until the appearances are normal. The surgeon can only come to recognise the necessary appearances of the cut surface of the nerve by actual practical experience. Before the sutures are introduced, the two ends of the nerve should be examined and an endeavour should be made to bring the corresponding parts into apposition. It is important to avoid torsion of either end of the nerve. Corresponding bundles can often be recognised in the upper and lower ends, and if possible the suture should be carried out in such a way as to bring these into contact with each other.

If the ends of the nerve come together without tension the perineurium may be sutured forthwith, four or more sutures being passed carefully through the sheath only, thus drawing it together around the nerve bundles, which must be entirely enclosed. A fully curved intestinal needle threaded with fine thread (120) is the best.

If there is a certain amount of tension a suture of stronger thread (60) or of No. 1 catgut should first be passed right through each end of the nerve and tied just sufficiently tight to bring the ends

into apposition; the sutures through the sheath can then be inserted and tied; if they give a secure hold the tension suture had better be removed; if, however, it appears doubtful whether the sutures in the sheath are strong enough to withstand the strain, then the tension suture should be left. If it is to be left an absorbable catgut suture is most suitable.

The question which next arises is whether the nerve should be left uncovered, or whether it should be enclosed in some adventitious substance to prevent the formation of adhesions. When it has been possible to excise all the scar tissue, so that the nerve lies in healthy surroundings, it is quite unnecessary to enclose it. If there is scar tissue which cannot be removed, or if the nerve will lie in contact with bone, it should either be displaced into healthy surroundings, or else a flap of subcutaneous fat should be cut and sutured around it. Foreign material, such as Cargile membrane, wax, etc., should not be used; they only tend to increase the formation of new fibrous tissue.

Closure of the Wound.—The deep fascia or muscles should be drawn together with a few catgut sutures after all bleeding points have been tied (careful hæmostasis is important); the skin may then be sutured by any of the ordinary methods.

The limb should be fixed on a splint in such a position as will relieve tension on nerve. For example, after suture of the median or musculo-spiral nerve, the elbow should be fixed in the flexed position. This position is maintained for six weeks and then gradually relaxed.

Nerve Grafting.—When it is impossible to bring the ends of the nerve into apposition and to suture them, the only reasonable procedure is to introduce a graft from another nerve from the same patient. As the surgeon gains experience in nerve suture, he finds fewer and fewer cases in which suture is impossible. Free exposure of the nerve, steady traction on the ends, and the use of a flexed position of the joint will allow a satisfactory suture in almost all cases, unless several inches of the nerve have been destroyed. In the occasional cases in which suture is impossible various procedures have been tried, such as—

(*a*) Splitting the distal end of the nerve and turning one half up to be sutured to the proximal end.

(*b*) Implanting the distal end into a slit on the side of a healthy nerve.

(*c*) Bridging the gap by enclosing the two ends of the nerve in a tube of fascia or in a piece of vein.

All these methods are to be condemned as irrational. The only rational method is to use a graft from a nerve that can be spared and to bridge the gap with this. Attempts have been made to use as a graft portions of nerve taken from an amputation stump of another patient; so far these have been unsuccessful; it is better to take the graft from a nerve that can be spared in the patient himself. The best nerves to use for this purpose are the internal cutaneous and the radial in the upper limb, the musculo-cutaneous (below the branches to the peronei) and the long saphenous in the lower limb; one or more strands of these nerves may be used.

It has been suggested that the junction of the lower end of the graft to the distal end of the nerve will become blocked by the formation of scar tissue before the axis cylinders from above have had time to reach it, and that this will form a barrier to their growth. If the examination of a grafted nerve shows that there is evidence of regeneration by the progress of formication down to the level of the lower end of the graft, but not beyond it, then it will be as well to perform a second operation, excising a portion of the reconstituted nerve at this level and resuturing.

Treatment of Nerves that are Undergoing Regeneration.

Physical Methods.—The regeneration of a nerve is a natural process which is not appreciably affected by any physical treatment; possibly it is assisted by good vascularity of the limb; no doubt also complete disuse of the limb by diminishing the vascularity delays it, therefore any treatment which will ensure the limb being kept in good condition is desirable, and it is important that such use should be made of the limb as is compatible with other essential forms of treatment.

The chief aim of physical methods of treatment is to preserve the nutrition of the muscles and the mobility of the joints and tendons. There is no doubt that the nutrition of the muscles is best preserved by giving daily electrical treatment of such a nature as will cause a regular series of contractions in the paralysed muscles. When these react only to a galvanic current, the treatment must be carried out by means of this current, the muscles being stimulated directly and the current being interrupted by a metronome, or being varied in strength and made to surge up to a strength which induces the contraction and then down again. Stimulation of the individual muscles is essential, and the current must be regulated so that it does not spread and cause contractions of other

groups. The use of electric baths, which are much in favour, has the advantage of simplicity, but by this method the stimulation is made to all the muscles, healthy as well as paralysed, and there is considerable risk that the daily stimulation of the healthy muscles will assist in producing a contracture of these muscles and a fixed deformity.

When the muscles are also being treated by support upon a splint the electrical treatment should be given without the removal of the splint, or, if this is impossible, the limb must be temporarily supported during treatment in the position which the splint is used to maintain. For example, in paralysis of the deltoid it is customary to keep the arm abducted at the shoulder to a right angle; the electrical treatment of the muscle should be carried out with the arm in this position on an abduction splint; in the same way in musculo-spiral paralysis the wrist is kept hyperextended upon a cock-up splint. The electrical treatment should be carried out with the hand resting upon this splint, or if the splint is removed, with the hand supported in the same position upon a pillow. The necessity for maintaining this position during electrical treatment is another argument against the use of the electric bath. As soon as the muscles show a reaction to stimulation with the faradic current they should be treated with this instead of with the galvanic current. Faradic stimulation is best given by direct stimulation of the muscle, the current being varied by the insertion and withdrawal of a heavy core into the coil. This method of stimulation with a surging current, popularised by Bristow, is particularly painless, and can be regulated with the greatest ease.

Massage may be used for the treatment of a regenerating nerve with two objects: (1) the improvement of the nutrition of the muscles, and (2) the prevention of adhesions around the muscles, tendons and joints, or the improvement of these adhesions if they have already formed. Massage of the nerve itself can do little good, and may do harm. Gentle massage over the scar may assist in loosening this and rendering it mobile, but deep massage over the point of suture is not advisable.

The final treatment of a regenerated nerve after the muscles have recovered voluntary power and response to faradic stimulation consist in re-educating and strengthening the movements. When this stage of the recovery has been reached a portion of each daily treatment should consist in the performance of voluntary movements under supervision, all the natural movements in which the muscles affected take part being carried out. Later, when a little voluntary control has been gained, the patient should be made to utilise the

limb for active work, either natural hand work or work in a gymnasium. This functional re-education is an essential part of the treatment if the best final results are to be obtained.

Postural Treatment.—A muscle that has been paralysed may fail to recover so long as it is overstretched either by the action of gravity, or by the contraction of its opponents; this is particularly noticeable in a temporary paralysis produced by compression of a nerve. Wrist-drop due to pressure upon the musculo-spiral nerve by crutches normally recovers in a period of from six weeks to three months; if, however, the wrist, fingers and thumb are held in a fully extended position upon a splint so that the extensor muscles are preserved from stretching, and if this position is maintained and never relaxed, recovery may take place in two or three weeks. The importance of this maintenance of a particular posture in the treatment of paralysed muscles has been specially taught by Sir Robert Jones and cannot be overestimated. Apart from this use of posture, however, there is a tendency, when one group of muscles is paralysed, for the opposing group to pass into a condition of permanent contracture, and thus to produce a fixed deformity. This is particularly noticeable in paralysis of the anterior tibial group of muscles, in which there is a great tendency to contraction in the calf muscles, with the consequent production of a fixed talipes equinus. The use of splints in nerve injuries may therefore be said to have two objects: first, the relief of paralysed muscles from tension, and, second, the prevention of a fixed deformity by contraction of the opposing muscles. The particular positions in which the limbs are splinted for special paralyses will be indicated in considering paralysis of individual nerves.

CHAPTER IX

INJURIES OF THE MUSCLES, TENDONS, AND SKIN

Loss or Paralysis of Muscles.

The extensive wounds produced in this war frequently cause a complete loss of action of a muscle or a group of muscles either by the destruction of the muscle substance itself, or by the separation of a muscle from its attachments, or by division or destruction of the tendon, or by damage of the nerve supply. A not uncommon example of complete destruction of a muscle is furnished by the deltoid. In some cases this is completely destroyed by an extensive wound of the shoulder; in others its attachment to the humerus is destroyed; in others, again, the circumflex nerve is divided and the muscle thus paralysed. Destruction of the muscles arising from

Fig. 38.—Injury of the back of the forearm causing destruction of the portion of the extensor communis digitorum which extends the ring and little fingers.

the external condyle of the humerus (supinator longus, extensor carpi radialis, etc.) is also not uncommon, and destruction of the tendons around the wrist and ankle is, of course, extremely frequent. In some cases there is both destruction of the muscle and of its nerve supply; an injury of the outer side of the leg may in this way damage the musculo-cutaneous branch of the external popliteal nerve, and, because the peroneal muscles are also destroyed, it may be useless to attempt to suture the nerve.

In considering muscle injuries, it is first necessary to decide whether the loss of the muscle seriously affects the utility of the

limb. For example, the loss of the deltoid muscle may render the arm, which is elsewhere strong, practically useless; whilst the loss of the supinator longus may be considered as a mere minor disability. Supposing that there is a considerable disability, is it possible either to replace the muscle or to compensate for its loss in some other way?

The replacement of the lost muscle may be carried out by the following methods :—

1. *Restoration of Continuity in the Muscle and Tendon.*—It may be possible to restore the attachments, or repair the gap in the muscle, or to suture divided tendons; that is to say, directly to repair the continuity of the muscle itself. This method is particularly applicable around the shoulder, where it is not uncommon to find that the loss of a portion of the clavicle, acromion, or spine of the scapula has left a part of the trapezius, or of the pectoralis major, or of the deltoid without any attachment. It is often possible to reattach a muscle thus separated either to its original point of attachment, or, at least, to a neighbouring point, which will serve as well.

Simple tendon repair requires very little comment; it is only necessary to remark that it is essential that the portions of the tendon to be sutured should be completely separated from scar tissue, that they should be sutured in as great tension as possible, and that, if there is scar tissue around them, they should be covered with a layer of fat, either cut from a neighbouring part or transplanted from a distance.

2. *Transplantation of Muscles or Tendons.*—When a muscle or its tendon has been so completely destroyed that it is not possible to reconstruct it, or when the muscle is paralysed and it is impossible to suture the nerve, or when nerve suture has failed, it may be practicable to replace the muscle by transplanting some other neighbouring muscle, so that the transplanted muscle may carry out its work. Transplantation of muscles and tendons have a comparatively limited scope, many of the transplantations that are done are worthless; some are even worse; they remove the action of a useful muscle and fail to restore the lost function. In considering the possibility of transplanting a muscle or tendon it is necessary first to determine whether there is any muscle in the neighbourhood that can be spared; then we must make up our mind whether this muscle can be brought into an alignment that will enable it to do the required work, and, finally, we must estimate whether in this altered position it will have sufficient power to carry out the necessary action. In the upper limb there are many good transplantations possible—for example, when the deltoid is lost

the clavicular part of the pectoralis major can be transplanted in such a way as to replace its anterior fibres. This transplantation is very successful provided that the supraspinatus is still present. and that the shoulder joint is itself intact. If the head of the humerus has been damaged and the supraspinatus lost it will usually be better to fix the shoulder joint. In the forearm, paralysis of the extensors of the thumb due to injury to the posterior interosseous nerve may be treated by transplanting other tendons into those of the individual thumb extensors. Transplantation of the palmaris longus into the extensor ossis metacarpi pollicis is an excellent example of a good transplantation. A method of carrying out this operation may be taken as an illustration of the essential points in the technique of tendon transplantation.

Technique of Tendon Transplantation.—The tendons may be exposed by a single incision, which passes around the radial border of the hand from the styloid process of the radius to the tendon of the palmaris longus, and thence extends vertically up the flexor aspect of the forearm for about three inches. The palmaris longus is exposed, divided at its lower end, and cleared for the full length of the incision. The tendon of the extensor ossis metacarpi pollicis is exposed immediately above the point at which it enters the groove in the radius; it is not divided, but a longitudinal slit half an inch long is made into it; the cut end of the palmaris longus tendon is passed through this slit and held on the distal side with a pair of Kocher's forceps. One assistant now holds the thumb fully extended and abducted, and with the other hand pulls strongly on the palmaris longus tendon. The second assistant, with another pair of Kocher's forceps, pulls upon the extensor ossis metacarpi pollicis. keeping up the extension of the thumb: in this position the tendons are sutured by passing a needle threaded with No. 60 linen thread through both halves of the extensor ossis metacarpi pollicis tendon. and through the tendon of the palmaris longus as it passes through the slit; this ligature is inserted and tied. The palmaris longus tendon is then laid alongside the tendon of the extensor ossis metacarpi pollicis distal to the point at which it perforates it: with a second suture both tendons are here again transfixed, the suture

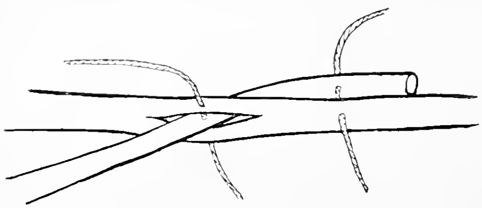

FIG. 39.—Diagram of the method of fixing a transplanted tendon by passing it through a slit in the tendon to which it is to be attached.

is wound completely around the tendons and tied; any redundant part of the palmaris longus tendon may then be cut off. The skin is sutured and the hand fixed upon a long cock-up splint, with the thumb abducted. It is kept in this position for six weeks to enable the point of suture of the tendon to become quite strong before any strain is put upon it.

The principles upon which the surgeon must act in any tendon transplantations are—

(1) To free the transplanted tendon sufficiently far up to enable it to take a good straight line to its new point of insertion.

(2) To leave the tendon to which the transplantation is made intact, and to transplant into it above any bridge under which it passes, such as the annular ligament.

(3) To suture the tendons with as much tension as possible, the proximal end of the transplanted tendon being pulled upon as well as the distal end of the tendon into which the transplant is being made.

(4) The suture must be very secure; the method of passing one tendon through the other and suturing it at the point of perforation, and also beyond this, is a good one. Another excellent method is to pass the transplanted tendon through the slit and to suture it there, and then turn the end back and suture it to itself.

In ordinary orthopædic surgery, in transplanting tendons for infantile paralysis, it is the rule, whenever possible, to transplant into bone; this is not necessary in transplantation in war wounds, because the tendon into which the transplant is being made is not a small atrophied tendon, such as is met with in infantile paralysis.

(5) If possible, the incisions should be arranged so that no scar is left exactly over the point of suture.

(6) The limb must be fixed in such a position as will relieve the sutured tendon of all strain, and this position must be maintained for six weeks.

3. *Tendon Fixation.*—In some cases it is impossible either to suture the muscle or its tendon, or to transplant another to replace it; we may then be able to lessen the disability by fixation of the proximal end of the tendon to the bone. The best example of this is in cases of complete paralysis of the peronei, with destruction not only of the nerve but also of a large part of the muscles themselves; a good foot can then be obtained by fixing the proximal ends of the tendons of the peronei to the fibula with sufficient tension to hold the foot in slight valgus. The tendons are exposed over the lower end of the shaft of the fibula and divided, a hole five-eighths of an inch in diameter is drilled through the bone and each tendon in turn is

passed through this, turned back, and sutured to itself. The foot must be fixed in the abducted position for a period of six weeks. This operation will often enable the patient to dispense with the use of any surgical apparatus.

4. *Arthrodesis.*—When none of the above proceedings are possible it may be advisable to fix the joint by the operation of arthrodesis. In rare cases this may be necessitated by the simple loss of one or more muscles; for example, in complete loss or paralysis of the deltoid, if it is impossible to transplant the pectoralis major, a very useless arm may remain. Full functional use for many purposes can, however, be restored if bony ankylosis of the shoulder is brought about, movements of the scapula serving to replace those of the shoulder joint. More often arthrodesis is indicated in cases in which, in addition to the destruction or paralysis of muscles, there has been actual extensive loss of bone. The condition then comes under the category of a flail joint.

The description of the methods of arthrodesis will be found in the chapters on repair of the upper and lower limbs.

5. *Surgical Appliances.*—The use of a supporting appliance to be worn permanently should be reserved for those cases of loss or paralysis of muscles in which no improvement can be brought about by other means. Appliances are designed either to fix the joint in a useful position, or else to leave the joint mobile, and to replace the loss of muscles by springs or accumulators; active movements can then be carried out by the use of the intact opposing muscles, the limb being brought back to its standard position by the spring whenever muscular action ceases. As an example of the use of an appliance to stiffen a joint, a moulded leather splint applied to a flail elbow may be cited. As an example of an appliance with a spring, a boot with a double iron and a toe-elevating spring used for complete paralysis or loss of the extensor muscles of the foot.

Adhesions of Muscles and Tendons.

Three varieties of scarring may be recognised as interfering with the action of the muscles.

1. *Extensive Superficial Scars.*—These are adherent to the muscles, so that they are pulled upon during muscular action and so restrict certain movements. Such scars are common around the shoulder, in the forearm, and in the thigh. They can, to a large extent, be avoided by the use of various methods of secondary suture. When present they should be treated by massage, by softening with simple ointment, and by persistent stretching; the stretching may be

manual, or may be a process of gradual stretching by the use of a splint. Forcible stretching under an anæsthetic is useless and may be detrimental, for a scar cannot be stretched suddenly; it will most probably rupture or be so attenuated that it will subsequently ulcerate. If these large scars do not yield to gradual stretching, or if they ulcerate, they should be treated by excision, the muscle underlying them should be freed, and the space thus left covered either by simple suture, after undercutting the skin around, or else by turning skin flaps from the neighbouring part over them, or, if these methods are inadequate, by the use of a flap from the surface of the abdomen or chest wall.

2. *Deeper Scars with Matting of the Muscles or Tendons.*—In these cases, again, treatment should be mainly by persistent massage and stretching. The use of splints as a means of keeping up continuous stretching is here particularly indicated. It is seldom advisable to attempt to dissect out all the scar tissue and to separate the muscles when the latter themselves are involved. The separation of scarred muscles from each other is exceedingly difficult, and there is a serious risk of interfering with their nerve supply. It is another matter with tendons; firm adhesions between tendons, or of tendons to other structures, are extremely resistant to stretching, and a dissection of the tendons from each other will often yield a very good result. In large scars of the forearm, in which muscles, tendons, and skin are densely matted together, it is often advisable to commence by operating, excising the scar in the skin, and freeing it from the muscles, separating the tendons from each other, but leaving the main part of the muscles themselves untouched. Further mobilisation may then be carried out by persistent massage and stretching.

3. *Simple Deep Adhesions of Tendons.*—In many perforating wounds of the forearm and of the ankle region careful examination will show that certain particular movements, both active and passive, are limited. These movements may indicate that one or more tendons are adherent, so that a movement in which they are stretched is passively obstructed, and a movement which they should carry out is actively impossible. Sometimes such an adherent tendon will pull through the scar and carry out its movement through a limited range. Electrical stimulation of the suspected muscle, by producing a full contraction of the muscle, but a very small active movement, may assist in the diagnosis. Such a limited adhesion of one or more tendons is particularly amenable to treatment by operation. A good example is furnished by the case of a man in whom a bullet entered the front of the wrist on the radial

side, and passed out about one inch above the wrist on the ulnar side. Some months afterwards the hand was perfect, except that, on full extension of the wrist and fingers, the terminal joint of the index finger remained flexed. On three successive occasions this finger was fully and completely extended by splinting, but each time the deformity recurred within a few days of the removal of the splint. Dissection of the front of the wrist showed that the bullet had passed beneath the tendon of the flexor profundus to the index finger, and that this tendon was densely adherent, without, however, being itself injured. The adhesions were divided and the finger kept in the fully extended position for a fortnight; the deformity of the hand was by this means completely cured.

Injuries to the Skin.

The extensive loss of skin which occurs in some wounds results in the presence of large granulating areas, which may not heal well if left simply to their own devices. The present treatment of wounds by wide excision, if a primary suture or delayed primary suture is not carried out, leaves a similar granulating area. It will be as well here to consider the treatment of these areas by methods of delayed primary suture, secondary suture, or excision and suture.

Primary Suture.—When a wound has been excised before it is infected and has been cleaned thoroughly of all dead tissue and of tissue that is likely to die, as well as of foreign bodies, it can be safely sutured immediately; but experience has shown that such a primary suture is only advisable when the patient can be kept under the care of the surgeon who performs the operation sufficiently long for the wound to heal and the sutures to be removed. The treatment of wounds by early excision and primary suture has yielded excellent results.

Delayed Primary Suture.—When excision of the wound has been successfully performed, the area left may be packed with sterile gauze and the patient removed to the Base. In many cases a wound which has been thus prepared remains aseptic, and can be sutured successfully at any time up to forty-eight hours after excision; that is to say, at any time before granulations have formed upon the cut surface. The deep parts and the skin are sutured in turn, just as in a fresh wound, and an excellent result may be expected. If granulations have formed upon the wound a different treatment will be necessary, and the suture becomes a secondary one.

Secondary Suture.—Secondary suture may be defined as the suture of a wound which has reached the granulating stage. In most

cases such a wound will not be strictly aseptic; that is to say, bacteriological investigation will demonstrate the presence of micro-organisms in the exudate. The wounds of most patients as they arrive in England are in this condition of granulating infecting wounds, unless they have been successfully sutured at or near the Front.

In the early stage the deep granulating wound shows retraction of the skin edges, with shelving sides covered with granulations; perhaps some sloughs may be present, and in the deep part there may be pockets which may lead down to bone. At this stage, provided that there are no such sloughs or pockets and that no

Fig. 40.—Large granulating wound of the buttock resulting from excision of a wound track. There was no sloughing and no unopened pocket or bone injury.

bone is exposed, the wound may be safely sutured by the following method.

A long curved needle, such as a perineal needle, is threaded with very strong silkworm gut, passed into the skin three-quarters of an inch from one margin of the wound, run deep to the whole of the wound, and brought out three-quarters of an inch from the further side. Several such sutures are passed at distances of one inch to one and a half inches from each other, and each in turn is tied. The result is to bring the whole granulating surfaces of the sides of the wound into apposition and to approximate the skin edges; the granulating surfaces adhere and the wound heals rapidly. The important point in this method is that the suture does not appear in the wound at all, so that its track does not become infected. The approximation of the whole of the granulating surfaces leaves no

pockets for the collection of pus; any extension of the area of infection is therefore avoided.

If this method has not been carried out but the wound allowed to granulate, it alters in character, becomes more opened out and its surfaces flatter and less shelving; at the same time the granulations become organised and epithelium creeps over them from the edges. In

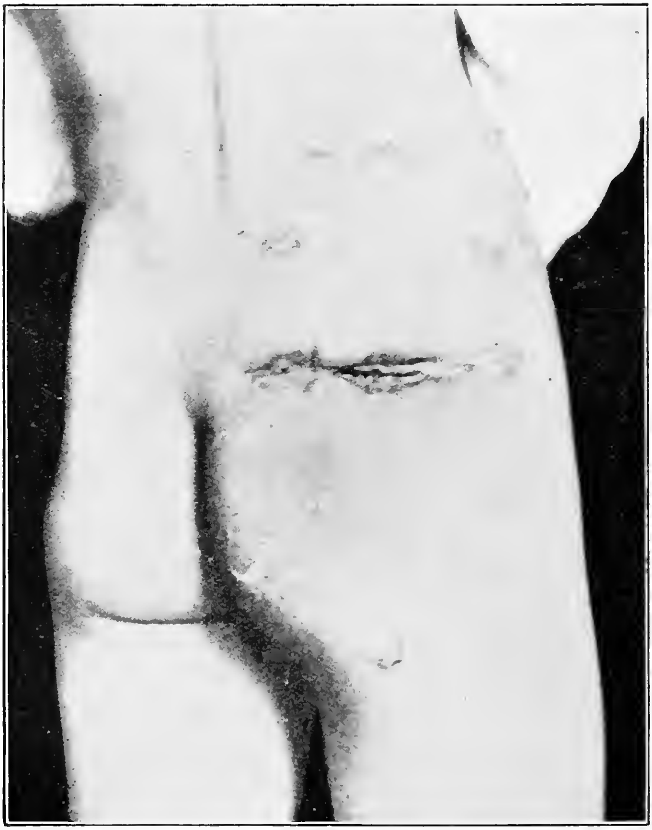

FIG. 41.—The scar resulting from secondary suture by under-running sutures of the wound shown in Fig. 40.

this way there results a flat granulating ulcer with some new fibrous tissue beneath the granulations and with the skin edges adherent to the deep tissues. If there are no deep pockets, and if the bone is not involved, this wound may still be sutured, but a different method will probably have to be used.

By pressing the skin around towards the granulating surfaces the latter may perhaps be induced to fold in; in this case the method

of under-running the whole wound with sutures, which has already been described, may be attempted. Perhaps it will not be possible to bring the skin edges completely into apposition, but if they can only be approximated the result will be greatly to diminish the time taken in healing. Instead of attempting this method one or other of the following methods may be used :—

1. The growing margins of the epithelium may be excised and removed, and the skin around undercut and freed until it will meet over the granulating area. The whole wound is then washed with methylated spirit and rubbed lightly with BIPP, and the skin is then sutured, the special suture described in Chapter I being particularly good for this purpose. A small indiarubber drain should be inserted at one place. This method leaves the granulations untouched, leaving, in addition, any new fibrous tissue which has already been formed beneath them; therefore, the amount of deep scarring which has already arisen is allowed to persist.

2. Instead of leaving the granulation tissue, this may be removed by shaving it off when the epithelial edges are cut away; any new fibrous tissue lying beneath the granulations may be excised, and the deep structures may be freed from each other so far as this can be done without damage. The wound is then treated with BIPP and sutured with a small drain.

Secondary suture is only possible when the wound is completely opened and is clean and granulating; if any pockets are present, and particularly if dead bone, or bone which is possibly dead, lies deep in the wound, secondary suture is impracticable. It may also be impossible when important nerves and vessels are exposed in or under the granulations. Wounds such as these are best left to granulate until all dead bone has had time to separate, until the pockets have filled up, and the marginal epithelium has grown in for a considerable distance. During this time the wound contracts so that, eventually, a scarred area is left which is much smaller in size than the original raw area, but which still has at its centre one or more chronic ulcers; the whole area may in time become covered with epithelium, but often the contraction of the peripheral scar tissue deprives the central ulcer of its proper blood supply and prevents it from healing. When the ulcer has reached a stationary condition, the operation of excision and suture should be undertaken.

The whole scarred area of the skin must be excised, the incision being carried close around it through healthy skin. The scar and ulcer may be excised deeply if it is known that there are no important structures immediately beneath. If, however, important

Fig. 42.—Very extensive wound of the shoulder, the whole of the acromion, outer half of the clavicle and of the spine of the scapula were lost, as well as the head of the humerus and upper part of the glenoid cavity. The necrotic upper end of the shaft of the humerus could be seen in the outer part of the wound. The field card stated that initially the axillary vessels and nerves were exposed. There was, however, no nerve injury.

vessels and nerves were exposed in the wound, the excision must be superficial and the deep scar must be left unless it is possible to

FIG. 43.—The condition of the wound after all necrosed bone had separated and healing had taken place except for a central ulcer which was adherent to the projection formed by the remaining part of the glenoid cavity. The ulcer failed to heal.

dissect a nerve out of the scar at the same time. When the excision has been completed, the skin around is undercut, flaps cut, if necessary, and the wound sutured. The performance of an excision of this sort in the case of a large wound, such as that shown in

Fig. 44.—The condition left after excision of the whole scar, suture of the trapezius, deltoid and pectoralis major to each other at the centre of the wound, and suture of flaps of skin. An attempt was made to ankylose the shaft of the humerus to the scapula, but this failed. The skin was easily made to meet over the raw area, and healed by first intention except for a small central area where suppuration occurred.

Figs. 42 to 45, may be a very formidable operation. Definite rules of procedure will, however, enable such operations to be carried out with comparative ease, and with very great benefit to the functional

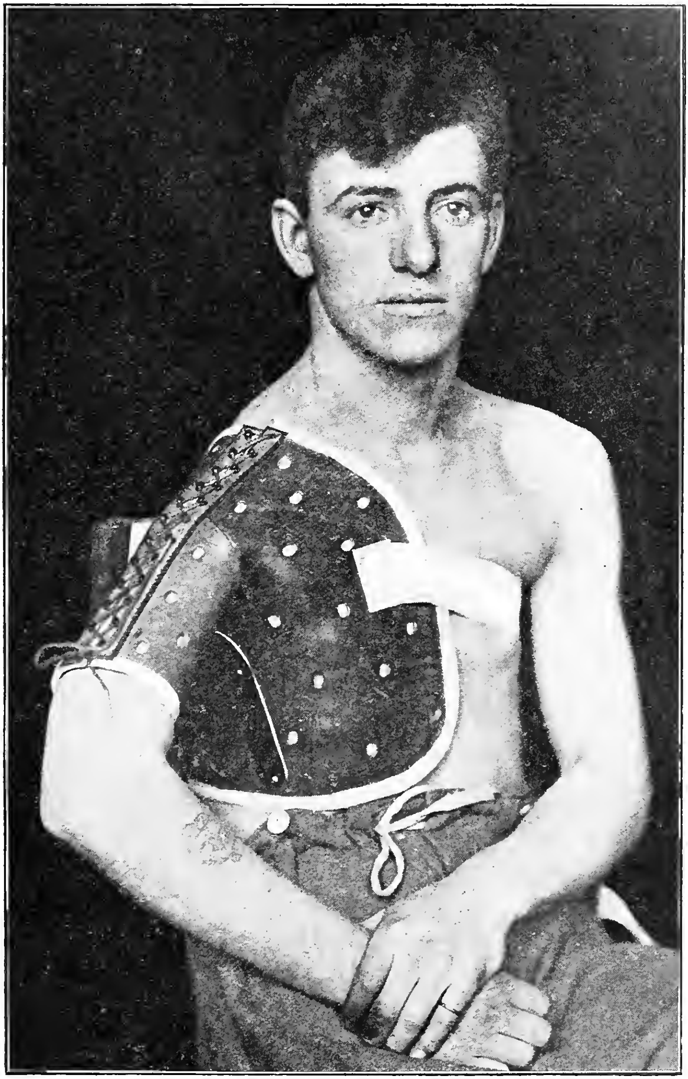

FIG. 45.—The shoulder enclosed in a moulded leather splint, which enabled the elbow and hand to be used.

condition of the wounded part. These rules may be briefly stated as follows :—

1. Excise through healthy skin, removing all scar.

2. Treat the scar and the ulcer as an infected area. Cauterise the ulcer with pure carbolic, if desired. Do not touch the ulcer

with any instrument or swab that is subsequently allowed to touch the rest of the wound, and raise the scar tissue and ulcer, if possible, without button-holing it, and without allowing the part removed to touch the new raw area.

3. Plan the flaps required and the method of suturing in advance.

4. Cut flaps, if possible, with their attachments at the proximal end of the limb and leave all possible fat attached to them.

5. Suture with the best possible apposition of skin edges. Avoid inversion of the skin and use tension sutures, as well as a continuous or numerous interrupted sutures.

6. Undercut skin freely and avoid any great tension, particularly on a flap.

7. Drain freely to avoid the formation of a hæmatoma under the skin.

8. Never hesitate to leave small uncovered areas if the suturing cannot be completed without tension.

9. Include with the excision any replacement of muscles to their attachments, and, if necessary, remove at the same time bony prominences which are serving no useful purpose, but which interfere with complete suture.

Skin-grafting has comparatively little scope in military orthopædic surgery. In certain regions—for example, on amputation stumps—it is absolutely contraindicated. The scar left by a skin grafting operation is not very sound, is easily ulcerated by friction, and is almost always adherent. Skin-grafting should be reserved for occasional cases of wounds over muscular regions, which cannot be covered by undercutting skin or by the use of skin flaps.

CHAPTER X

FUNCTIONAL DISABILITIES

In separating disabilities into two groups, organic and functional, we mean that in the former there is a traumatic or pathological condition which is sufficient fully to account for the disability, whereas in the latter or functional class there is no such organic change, or at least the organic change is insufficient to account for the symptoms. From this we may presume that in the functional disability the initiation of use in the higher nerve centres is interfered with, not necessarily by any voluntary action on the part of the patient, but as the result of reflex or subconscious inhibition. If the condition was voluntary it would be more properly described as malingering, but it is quite clear that functional disability and true malingering are entirely separate things, and that in the former the disuse or misuse of the affected part is quite beyond the patient's control.

The simplest functional disabilities are those which are due to habitual disuse of a limb which has been injured, the disuse often having involved the maintenance of a limb in some habitual position which has become permanent. A good example of the origin of such a functional disability occurs in the disuse of the lower limb occasionally seen after simple flesh wounds. When the patient first leaves his bed he is unable, or unwilling, to stand upon the injured limb; he is given a pair of crutches, and he walks upon the sound limb with the aid of these; to keep the foot clear of the ground on the damaged side he raises the pelvis and adducts the hip, thus producing an apparent shortening of the limb. After a time he begins to put the foot to the ground and to walk upon the leg, but the adduction of the hip has now become habitual and the patient is unable to overcome it; the limb remains apparently short, and at each step upon the damaged leg the body tilts over towards the affected side. The resulting functional deformity is exactly similar to that often seen in hysterical girls, and known either as functional scoliosis or as functional adduction of the hip. Sometimes such a case comes into the hands of an ignorant member of the profession,

who prescribes for him a high boot to correct the apparent shortness of the limb; this, by increasing the adduction of the hip, renders the deformity still more severe, and more difficult to cure.

The first step in the treatment of such a case is to make quite sure that there is really no obstruction to full movement in the hip joint. It may be possible to ascertain this by a simple clinical examination, but it will be better to give an anæsthetic, both because by this means we can be more certain of the facts, and also because it is often possible to persuade the patient that the manipulation which has been done while he is under the anæsthetic has put his hip right. Having by means of the anæsthetic proved that mobility is free, the rest of the treatment consists in persuasion and re-education.

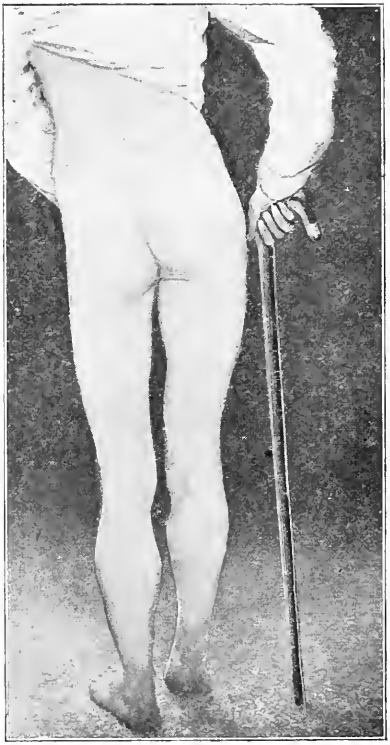

Fig. 46.—Functional adduction of the right hip following an old arthritis of the joint, possibly tuberculous in origin. There was no real restriction of movement.

This simplest type of functional disability illustrates both the mode of origin (disuse and habitual posture) and also the conditions present in all functional deformities. In a functional deformity a joint is kept in one fixed posture by muscular spasm. A functional disability may be due either to flaccidity of muscles or to spasm of muscles, or to a combination of flaccidity of certain muscles with spasm of their opponents. Roughly, we may speak of cases in which the muscles are flaccid as instances of functional paralysis, and those in which the muscles are in a condition of spasm as a functional deformity. Either of these may be accompanied by an alteration of sensation, which usually consists of a complete anæsthesia to touch, pin-prick and pain, which is not limited to the distribution of any particular nerve or nerves, but ceases at a line which surrounds the limb at practically a uniform level.

These functional deformities which have resulted from simple

disuse are comparatively easily treated; this is not true of the more severe type in which there is considerable spasm in some muscle or group of muscles, and in which an attempt to overcome this spasm and to correct the deformity produces severe pain. It is most important that in such cases a very full examination of the whole of the damaged limb, and particularly of its nerves, should be carried out, and also that the movements of the joints of the limbs should be tested under anæsthesia. If the nerves are found to be quite painless on pressure and the joint movements perfectly free, we may hope that the demonstration of this freedom of movement may succeed in persuading the patient of the possibility of his cure. Thus a patient came under my care after being in hospital abroad, where it had been suggested that he had tuberculous disease of the shoulder. The shoulder joint was held perfectly stiff, with the arm by the side and the elbow fully extended, any movement in the shoulder or elbow being violently resisted. No evidence of disease could be found, and skiagrams showed the joints to be perfectly healthy. Under an anæsthetic the shoulder and elbow moved freely, the patient was allowed to come round with the elbow fully flexed and the shoulder abducted in order to demonstrate to him the possibility of these movements. A single treatment by re-educational exercises on the day following the anæsthetic resulted in complete cure, the man requesting to be sent back to duty.

FIG. 47.—Functional spasmodic inversion of the foot.

In many of the cases of functional spasm it will be found under the anæsthetic that adhesions are heard to snap in or around the joints that have been fixed; this fact demonstrates the importance of the preliminary anæsthetic in many of these cases, as these adhesions in themselves are certainly a barrier to cure. Often an investigation of cases of functional spasm will show that one or other of the nerves of the affected limb is tender at some point along its course. This is often true of those cases of spasmodic inversion

of the foot which are so common in soldiers after various sprains and injuries of the ankle region, as well as after attacks of trench foot. In one case of spasmodic inversion of the foot seen by me, the condition had followed trench foot, and the posterior tibial nerve and plantar nerves were definitely tender. The condition had persisted for fifteen months, and the patient had been discharged from the army. Under an anæsthetic the foot was manipulated straight and the sciatic nerve was stretched by flexing the hip and extending the knee. Immediately the patient came round from the anæsthetic he was made to walk with the foot flat. He never relapsed, and a fortnight's educational treatment completed his cure.

In many instances functional spasm or paralysis has followed a penetrating wound of the part of the limb affected, but the wound is not such as to account for the disability. Great care must be exercised in diagnosing such conditions as functional. Four types may be recognised :—

1. Spasm of the muscles supplied by one particular nerve, and due possibly to a slight irritative lesion of the nerve, upon which a painful nodule may be felt.
2. A similar condition with a flaccidity of the opposing muscles and perhaps an anæsthesia of a functional type.
3. A muscular spasm not confined to the muscles supplied by an individual nerve, and unaccompanied by any evidence of nerve injury.
4. A muscular flaccidity, usually with an anæsthesia of a functional type and not confined to the muscles supplied by any one nerve.

Of these four groups the first is not a true functional lesion but a pure irritation of the nerve; the second consists in irritation of the nerve with a functional addition; in both these there are indications of nerve irritation, such as excessive sweating, and vasomotor changes may be present. The third and fourth groups are purely functional conditions.

Certain functional deformities are complicated by the addition of a clonic spasm; it occurs in the affected muscles either spontaneously or as the result of stretching of the muscle; such clonic spasms are an occasional accompaniment of the hysterical deformities of civil practice. The clonus is started by any effort on the part of the patient to overcome the tonic spasm, or by the application of external force in this direction. For example, a patient with an old wound of the head of the tibia had a functional spasm of the quadriceps muscle which completely prevented flexion of the knee;

any attempt that the man made to flex the knee produced violent clonic spasms in the quadriceps, resulting in a series of kicking movements; any effort to flex the knee forcibly by any externally applied force produced the same movements; under an anæsthetic all spasm at once ceased.

From these general remarks upon functional deformities it will be gathered that before the diagnosis can be made for certain the patient must be examined very completely, the area of the wound must be investigated, the nerves and vessels being specially examined, and an X-ray photograph should be taken to exclude the presence of any foreign body. The muscles require careful investigation, any spasm being particularly noted and the electrical reactions being tested. If in any muscles the response to faradic stimulation

Fig. 48.—Functional wrist drop. There had been a gunshot wound of the forearm which resulted in functional wrist drop with complete loss of power in the extensor muscles and anæsthesia of the hand up to the level marked upon the limb. The anæsthesia gradually contracted until it represented the area of distribution of the median nerve. The median intrinsic muscles showed the reaction of degeneration. On exploratory operation the median nerve was found compressed by scar tissue. This was an instance of an organic lesion with a functional addition.

is lost, an organic lesion must be present. The joint movements must be tested in almost every case while the patient is under an anæsthetic, for a reflex spasm or paralysis may be kept up by adhesions which are so slight that they cannot be detected by ordinary clinical investigation. The presence of trophic and vaso-motor changes should be noted as important evidence of an organic lesion. Finally, the patient's mental condition should be studied and every effort made to secure his confidence, and to find out from him in what particular ways he finds difficulty in resuming the use of the disabled part. The importance of this was shown in a recent case under my care: a pensioner suffered from complete disuse in the thumb, index and second fingers of the left hand,

which came on as the result of a gunshot wound of the arm above the elbow. He volunteered the statement that if the hand was behind his back he could not tell in what position these fingers were. Careful examination showed that he had complete loss of muscle sense and of sense of position in the radial side of the fore-arm and hand, due probably to an injury of the median nerve; the loss of this sense undoubtedly accounted for the disuse of the thumb and fingers, and led to the proper line of treatment by re-education of movement, assisted by vision.

In the course of the investigation an endeavour should be made to distract the attention of the man from the injured part, both by inducing him to talk of other matters and by making him carry out other movements. When the attention is thus distracted the muscular spasm, if it is due to a purely functional and not to a reflex cause, can be overcome with much greater ease.

It is impossible to lay down any fixed course of treatment for functional disabilities. The individuality of the surgeon, masseuse, or gymnast who is carrying out the treatment counts for much more than does any particular principle. Our objects must be first to exclude any actual pathological or mechanical difficulty, and then to persuade the patient that his condition has been put right; as in the treatment of ordinary hysterical deformities a certain theatrical element is sometimes very successful. This is particularly so when the patient ascribes his disablement to some such cause as a dislocation of a joint, or a displacement of a muscle. The manipulation of a joint, or other part, followed by a confident statement on the part of the surgeon that the dislocation is reduced, often results in an immediate and complete cure. Briefly stated, the principles of the treatment of functional disabilities may be put as follows :—

1. The manipulation of the affected part while the patient is under an anæsthetic, in order to make certain that there is no restriction of movement, and also in order to impress him with the fact that something has been done which will result in his cure. Gas or gas and oxygen is the best form of anæsthesia; it is sufficient for the purpose, and the rapid recovery of consciousness enables us at once to explain to the patient that the condition is now cured, and to put him through a simple exercise or two almost before he has had the time to recover completely from the effects of the anæsthetic.
2. No other form of local treatment should be used for functional deformities. The use of splints and of plaster of Paris as a

means of holding these deformities in a corrected position is not simply ineffectual, but is actually harmful, calling the patient's attention more to his condition, and usually increasing the severity of the spasm as soon as the splint or plaster is removed.

3. After the manipulation under the anæsthetic the further treatment should be purely persuasive, consisting in graduated educational exercises; these exercises should not be limited to such as will in themselves directly correct the deformity, but should be general, exercising the whole body. In particular an endeavour should be made to arrange such exercises as will distract the patient's attention from the damaged part, for when his attention has thus been effectually distracted the deformity will often disappear spontaneously. The use of games in the treatment of these patients is very great. If their interest can once be aroused the excitement of the game may completely cure the deformity, at least for the time being. It is not unusual to see a patient who is suffering from a functional inversion of the foot run with a perfectly normal gait, or one with a functional paralysis of the hand catch a football in his paralysed hand. The effect of the discovery by the man that he is able to do these things is very greatly to accelerate the rapidity of his cure.

CHAPTER XI

AMPUTATIONS

In surgery in general and in military surgery in particular amputations may be carried out under two very distinct conditions. They may be done under conditions which allow of strict asepsis, through uninjured and uninfected tissues and upon a patient in whom healing by primary union is to be expected. Or they may be done to save life, or to save a portion of an injured limb under such conditions as will render primary union doubtful, or may even indicate that it cannot possibly be secured. The level chosen for amputation in these two cases is not necessarily the same; in fact, it should be very definitely different. Whenever sepsis is present, whenever gas gangrene necessitates amputation, whenever the absence of facilities for operation renders asepsis difficult, there can be only one rule as to the level of amputation; that is to amputate at the lowest level that is consistent with safety. Experience shows that when primary union of an amputation fails or is impossible, secondary operations upon the stump will probably be required. These may take the form of the removal of sequestra or of secondary suture, but more often they consist in reamputation with the removal of a greater or less amount of bone, the original stump being thus shortened. If the primary operation in such a case has been carried out at a site chosen as a suitable one for the fitting of an artificial limb, then by the time the stump is finally healed the level will have been altered and the length of the stump will fall short of this optimum. It is common to find that a primary amputation through the lower third of the thigh, itself a very good level, results in one or more secondary operations leaving a short thigh stump which contains less than half the length of the femur. Similarly a Syme's amputation in which primary union fails will almost certainly result in secondary amputation through the middle of the leg, a very considerable loss to the patient. If a first amputation through the tarsus had been possible, then a secondary Syme's amputation might have been carried out when the sepsis had been controlled.

Whenever, therefore, a particular level of amputation is recom-

mended as a good one, it must be understood that this recommendation presupposes that there is a really good chance of securing primary union. If primary union is impossible, or if any doubt exists as to its probability, then it will be better to amputate at a lower level, if this is consistent with safety.

It is not my intention to deal with the subject of primary amputations. The question of whether or not primary union can be secured must depend upon the nature and extent of the injury, the presence of infection, and the condition of the patient, more particularly in regard to loss of blood and shock. These are matters for those concerned in the acute surgery of the war, and the decision must depend upon their experience. But it cannot be too strongly emphasised that whenever there is doubt it will always be better for the patient if as much as possible is saved, even if this necessitates a later reamputation.

Levels of Amputation.

When it is possible to choose the level at which an amputation shall be carried out, and the method of cutting the flap and dividing the bone, only one consideration should be allowed to influence us in our decision, namely, the functional utility obtainable in the part of the limb which can be saved. In certain cases—for example, in amputation of part of the hand or of part of the foot—the functional utility of the limb itself, without the assistance of an artificial appliance, is the point which has to be considered; but more often our concern is to leave a stump to which an artificial limb can be adjusted with comfort, and which will enable this artificial limb to be used to the greatest advantage.

A decision as to the best levels for amputation, therefore, presupposes a certain knowledge on the part of the operator of the methods of fitting artificial limbs and of the ways in which the stump communicates movement to these.

The method of amputating has also a bearing upon this point because the position of the scars, the covering of the end of the bone, and the presence of the attachments of certain muscles must affect the fitting of a bucket around the stump and the transmission of movement to this bucket.

Amputations of the Lower Limb.

Bearing Points.—As the function of an artificial leg is to transmit the body weight to the ground in standing and walking, this weight must be transmitted to the artificial limb by certain bearing points. Only particular amputation stumps can take the full weight upon

their extremity (*end-bearing*). Others are able to take a certain proportion of the weight upon the extremity (*partially end-bearing*). In the majority, however, the weight must be transmitted by pressure upon the bony points around the joint above the site of the amputation, *i. e.* around the knee in cases of amputation below the knee (*tibial-bearing*), or around the hip in cases of amputation through the thigh (*ischial-bearing*). The factors in a stump which favour end-bearing are—

1. Section of the bone at a level where it is cancellous.
2. A covering of thick fibrous or areolar tissue over the end of the bone.
3. A skin flap from a neighbourhood which normally bears weight.

In Syme's amputation all these three factors are present, and the stump is an ideal one, capable of withstanding the full body weight practically as well as the normal heel. Amputation through the knee joint also yields a very good end-bearing stump, and amputation through the condyles with an anterior flap is only slightly less satisfactory. The other amputations which are partially end-bearing are those through the upper third of the tibia and through the femur close below the trochanters. Of course, in many other stumps a small proportion of the weight can be borne upon the end of the stump upon a sling inserted in the bucket.

The bearing upon the tibia is the correct one for all amputations below the knee and above the level of a Syme. It is taken by a close fitting around the internal tuberosity and tubercle of the tibia and the lower margin of the patella, the fitting upon the outer side being less close because the head of the fibula is unable to stand much pressure. Many limb-makers prefer to take the weight in these cases through a leather thigh bucket, either by direct compression of the thigh or by carrying the bucket up to the level of the tuberosity of the ischium. This is a bad method, because it constricts the thigh muscles and makes the limb more clumsy and heavy. It is only adopted by limb-makers because they have not the skill to carry out the tibial fitting with sufficient accuracy. It should be reserved for exceptional cases in which the head of the tibia is unable to bear the weight.

In amputations through the thigh the bearing is taken chiefly upon the top of the bucket, which fits under the tuberosity of the ischium exactly as does the ring of a Thomas's splint. This tuberosity should rest either upon the edge of the bucket or upon a rounded ledge in its interior. The inner side of the bucket should curve downwards so as to clear the perineum, upon which pressure cannot be borne. Both the front and the back of the bucket slope upwards towards

the outer side, so that the highest point is over the great trochanter. The shape of the thigh bucket is important; it should enclose the stump accurately, without deforming it by undue pressure in any direction, as no mobility of the stump inside the bucket should be permitted. Looked at from the front a thigh bucket should be slightly concave on its inner side, and looked at from the side it should be concave posteriorly. These two curves increase the support given to the tuberosity of the ischium. A certain amount of support is given by the close circumferential fitting of the bucket to the stump, but if this close fitting is depended upon for bearing much of the weight the result is that the skin is drawn up very tightly over the end of the stump, which is liable on this account to become ulcerated, particularly if there is a terminal scar which is large or adherent.

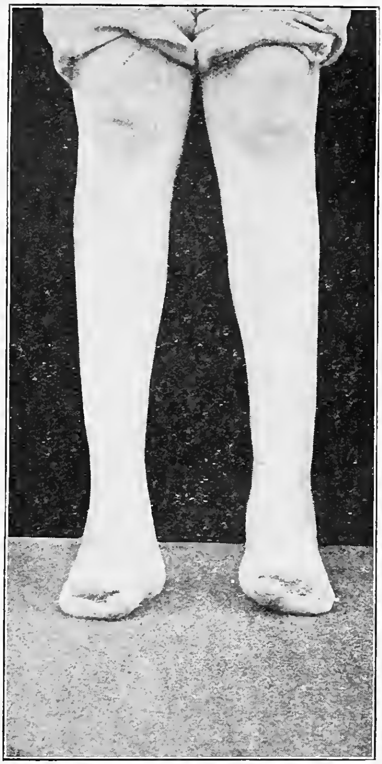

Fig. 49.—Amputation at the tarso-metatarsal junction in the right foot and through the tarsus in the left foot, for frost-bite. The stump on the left side has contracted into a varus deformity on account of the loss of attachment of the peroneal tendons.

Amputations of the Foot.—The normal foot has three important bearing points, the heel and the heads of the first and fifth metatarsal bones. The fact that in any amputation in which more than the toes are removed the anterior bearing points are interfered with is of very great importance, so much so that it may be argued that whenever the anterior part of the metatarsal bones has to be sacrificed a better result will be obtained by sacrificing the whole foot and performing Syme's amputation. A second important point in the consideration of amputation through the foot is the removal of the attachments of the tibialis anticus and of the peroneal muscles; when these have to be sacrificed, unless the tendons are reattached, the stump will almost certainly become contracted into an equino-varus position and the fitting of an artificial foot will be difficult or

impossible. The third point for consideration is the position and nature of the scars left. All scars on a foot stump should be dorsal, and the covering of the stump, particularly of its anterior extremity, with unsound or scarred skin should be considered as such a serious defect as to indicate amputation at a higher level.

Amputation of individual toes or of all the toes causes no great disability provided that the scars are sound. The fitting of a suitable boot in which the sole and the toe part of the upper are stiffened is all that is required to enable the patient to walk well. Lisfranc's amputation and similar amputations at the tarso-metatarsal junction are also good, provided that the scar is dorsal and that there is no unsound skin in a situation where it is liable to pressure or friction. Again a suitable boot is all that is necessary.

Chopart's amputation is not a very good one; unless the tendons are reattached there is always a tendency to contraction, so that the patient walks upon the outer part of the anterior end of the stump instead of upon the heel. In a large proportion of cases of this amputation, reamputation at the Syme level is necessary. When the tendons of the tibialis anticus, long extensors and peronei have been reattached and the stump kept in a good position a good result is obtained.

Pirogoff's amputation and similar amputations in which part of the os calcis is retained have no real advantage over Syme's amputation. They were designed in order to avoid shortening and to keep the prominent malleoli so that a simple boot might be worn and an elaborate artificial foot dispensed with. If such a simple boot is to be used then these amputations have a certain advantage, but when, as in military surgery, an artificial foot will be ultimately provided, a Syme's amputation will be better because the greater amount of shortening enables a better ankle joint to be inserted in the artificial foot. The best of this group of amputations is Gordon Watson's, in which the malleoli are kept and a part of the os calcis is wedged between them after the removal of the articular cartilage of the ankle joint. This is a good amputation for a poor man who will wear an elephant boot and not an artificial foot.

I have not seen a subastragaloid amputation in military surgery, but it seems that it would have the same objections as Pirogoff's amputation.

Syme's amputation is the best amputation in the lower limb. Some limb-makers object to it, but this is because it is more difficult to fit than a straightforward amputation through the middle of the leg. A patient with a good Syme's amputation can walk ten or fifteen miles in an elephant boot, and with a good artificial foot he

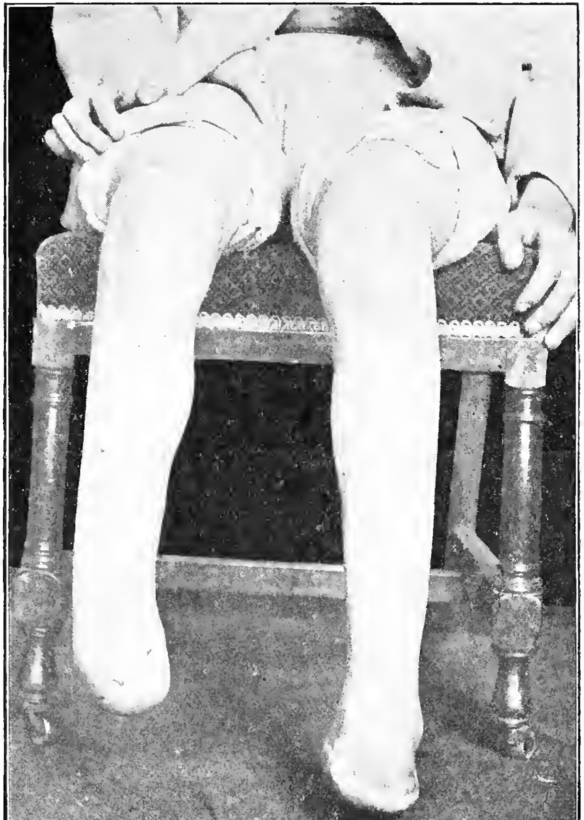

Fig. 50.

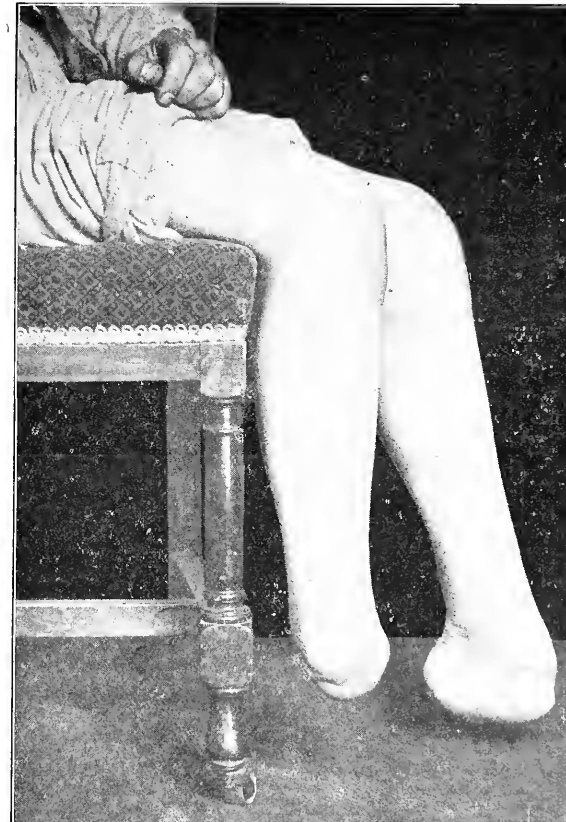

Fig. 51.

Syme's amputation on the right side, Chopart's amputation on the left. The Syme was a bad stump, the flap being cut too much from the inner side. The Chopart stump was contracted into the usual equino-varus deformity. Further operation was necessary, retrimming the stump on the right, reamputation (Syme's) on the left.

should be able to run, jump and play such games as tennis and golf almost on an equality with a whole man.

The classical Syme has too large a flap. The best incision is an elliptical one, the angle between the two lines of the classical one being abolished by taking the anterior incision up to a higher level and carrying the lower incision to within three-quarters of an inch of the point of the heel. A frequent trouble in a Syme's amputation is tenderness in the plantar flap resulting from the existence of the terminations of the plantar nerves therein. The nerves should be dissected back and the main posterior tibial nerve divided well above the level of the malleoli. It is most important that the heel flap should have a good blood supply; for this reason every care must be taken in removing the astragalus and the os calcis to cut close to the bone and to avoid injury to the vessels. If the blood supply of the flap is insufficient sloughing of its margin may occur, and this will very often necessitate a reamputation through the leg. Suppuration of a Syme's amputation is a very serious accident. If any necrosis of the lower end of the tibia or fibula occurs the stump will almost certainly not bear weight upon its end; either the patient must wear a clumsy limb with bearing upon the head of the tibia or he must submit to reamputation. For this reason Syme's amputation should never be carried out unless asepsis can be secured. In a primary amputation if the occurrence of sepsis is probable or even possible it is better to amputate at a lower level and to leave a reamputation at Syme's level to be done at a later stage.

Fig. 52.—A good Syme stump with complete end bearing and $2\frac{1}{4}$ inches clearance between the end of the stump and the ground.

Of Syme's amputation with an internal flap I have had little

experience. The cases in which it can be carried out with the prospect of securing primary union must be very few. Unless the resultant stump is end-bearing an amputation through the leg is preferable.

In the late stages of treatment of men who have been wounded in the foot it is often found advisable to amputate. This means that much time has been wasted and much unnecessary suffering put up with. It is worth while considering what conditions in a damaged foot might be taken as indicating an earlier amputation. In order that the foot should be thought worth saving we should be able to say that it will eventually be one upon which comfortable walking for several miles at a time is possible; if not, a Syme's amputation or an amputation through the leg would be better. Every case must be considered individually, but certain general principles will help to guide the judgment. The destruction of the bony bearing points of the foot, the heel and the heads of the first and fifth metatarsal bones is a very important loss, the loss of mobility of the ankle joint is a second point of importance, and the presence of thin, adherent, depressed or painful scars at points where they would be subject to pressure or friction also requires consideration. As examples we might instance that a patient in whom the ankle joint has been lost by suppuration and the first metatarsal bone removed, or in whom the whole inner side of the foot, including the great toe, has been sacrificed or in whom most of the os calcis has been destroyed, would in each case be better with an early amputation, particularly if the wound is septic and a prolonged period of hospital treatment, therefore, to be expected before the wounds could be soundly healed.

Amputations through the Leg.—The use of a leg stump is to hold and swing the artificial foot. The longer the stump the better the leverage it exerts in the bucket, but if the stump is too long it is simply an embarrassment because the bucket must be made proportionately large and clumsy in order to contain it. The best length of stump is that which contains about seven inches of the tibia.

The best flap is a well-padded muscular one which can be obtained from the posterior or postero-external surface, and which should be long enough to cover completely the end of the bone so that the scar is anterior or antero-internal. Equal lateral or anterior and posterior flaps leave a terminal scar and are apt to leave a flabby end to the stump. When the flaps have been cut rather long this flabby end often has a very poor circulation and tends to ulcerate, so that re-trimming may be necessary; this is particularly common in the lower third of the leg. The single flap advised should fit closely but without tension.

The tibia should have its anterior corner rounded, and the fibula should be cut shorter than the tibia. A stump in which the fibula is left long is a great inconvenience, and the error of leaving such a long fibula is a common one.

A short stump below the knee containing only two inches of tibia, measured from the joint margin, is worth keeping. The proper test

Fig. 53.—Skiagraph of a short stump below the knee. The fibula had been left longer than the tibia, and retrimming with removal of the fibula was necessary.

of utility of such a short stump is made by flexing the knee and testing whether in this position there is sufficient stump projecting beyond the hamstrings tendons to enable a finger to be hooked round it and to secure a firm hold. In these very short stumps the lower cut end of the fibula is sometimes tilted away from the tibia and becomes prominent. It is a good plan to remove the whole of the

fibula; this gets rid of a piece of bone which stands pressure badly, and by diminishing the bulk of the stump may allow a flap which would otherwise be too small to suffice.

These short stumps can bear a considerable amount of weight upon their extremity; for this reason terminal scars are particularly objectionable. But the preservation of even a short stump below the knee is so important to the functional utility of the limb that it is better to preserve such a stump even when the scar is unsound than to reamputate through the femur.

There is a great tendency for short stumps to become flexed at the knee. This should be avoided by the use of a splint immediately after the amputation. When flexion is established it can usually

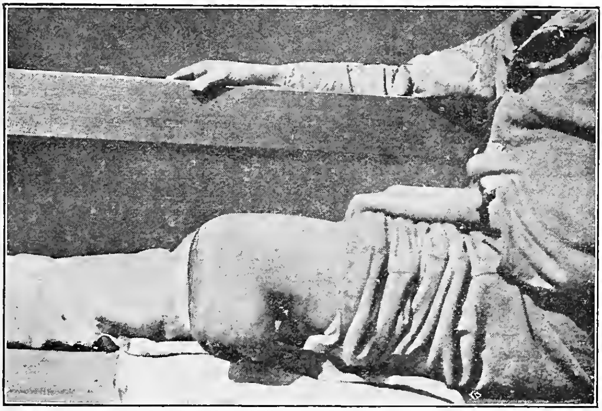

Fig. 54.—Amputation below the knee with the stump contracted into a flexed position. Open operation was necessary before the knee could be extended. The length of the stump was ample to control the bucket of an artificial leg.

be overcome by daily stretching with the hand and by the use of a posterior splint. If, however, the extreme limit of extension is less than 135°, operative treatment may be required. It will then be found necessary to divide the tendons of the hamstrings, the ilio-tibial band, the attachment of the gastrocnemius and the posterior part of the capsule before the knee can be straightened. This is best done through two longitudinal incisions on either side of the posterior aspect of the joint. The ends of the popliteal nerves should be removed at the same time. The operation is simplified by ligature and division of the popliteal vessels, but when this is done there is a liability to sloughing at the end of the stump, particularly if there is a weak adherent scar. For this reason it is better to preserve the vessels. As a rule good mobility of the knee from the position of

full extension to the right angle results, but active flexion is sometimes a little weak.

Some surgeons advise that in these cases the knee should be left flexed to a right angle and a kneeling leg fitted. This is a confession of failure, and practically leaves the man to lose the advantage that he should have gained by having his knee saved.

In amputations below the knee in which the knee joint is ankylosed a reamputation through the condyles of the femur will give the best result.

Amputation through the Knee.—Considered from the point of view of fitting an artificial limb this amputation has advantages and disadvantages. It gives a good end-bearing stump upon which a well-fitting limb is comfortable. The limb, however, is clumsy. Owing to the fact that the stump is larger at the end than it is a short distance up, it will not slip into a complete wooden bucket, so that part at least of the thigh piece must be made of leather. The knee joint must consist of outside steel joints which are heavy and which widen the knee to an unnatural extent. If the stump shrinks the thigh piece has to be remade and the lateral steels closed in, a much more elaborate alteration than that necessary for an ordinary thigh stump.

From the surgical point of view this amputation requires very long flaps and can only be carried out when a considerable area of skin below the knee is undamaged. It is a very risky operation when asepsis cannot be secured. Probably in a good many cases in which amputation through the knee has been performed it would have been possible to amputate through the tibia and to keep two inches of that bone.

The patella should be removed in this amputation, as it only embarrasses the thigh fitting. It appears to make very little difference whether the semilunar cartilages are left or removed, but if they are damaged they should be removed entirely.

When the skin is unsound over an amputation through the knee joint, or where end-bearing is impossible, it is better to reamputate through the condyles of the femur.

Amputation through the Thigh.—Undoubtedly the best amputation above the knee is that in which the bone is divided through the supracondylar ridges just where the femur is widening out. The best flap is an anterior one. When asepsis is complete the stump is improved if the superficial half of the patella is retained and pinned over the cut end of the bone (Stokes-Gritti amputation). But this is a danger if sepsis occurs, for the patella may fail to unite and become tilted, or necrosis may occur between it and the femur. In

the latter case the necessary removal of the necrosed bone is very difficult. If the patella is not used in this way it should be removed, as much as possible of the fibrous tissue around it being retained and stitched over the end of the bone.

This amputation is not a great favourite with limb-makers because the length of the stump interferes with their knee mechanism, but if the condyles are cut through at a sufficiently high level and covered closely with a well-fitting flap, they can get over this difficulty. The resulting stump is then a very good one, gives very little trouble, and will take a considerable part of the weight upon its end. For

FIG. 55.—Method of testing a thigh stump for flexion deformity of the hip. Extension was in this case complete.

amputations above this level the only rule is that the stump should be as long as possible, every inch saved in the thigh being of importance. A single long flap containing muscle is the best, and if there is any choice, this should be cut from the outer side, so that the scar is internal, where it is least liable to pressure; but as a rule flaps must be cut wherever skin is available. There is a great tendency to retraction of the muscles, leaving the end of the bone prominent and covered only by the skin, therefore the flap should be cut deeply and the muscles sutured over the end of the bone.

Thigh stumps, particularly if short, have a great tendency to become flexed and abducted at the hip joint. This deformity is

most important because it interferes with the stability of the artificial limb. It should be combated from the first by daily stretching,

FIG. 56.—Fixed flexion deformity of the hip joint, necessitating open operation before sufficient extension could be secured to allow of the fitting of an artificial limb.

commenced as soon as possible after the amputation. It is often hidden by compensatory lordosis and curvature of the lumbar spine. therefore it must be looked for by a routine method in which this compensation is prevented.

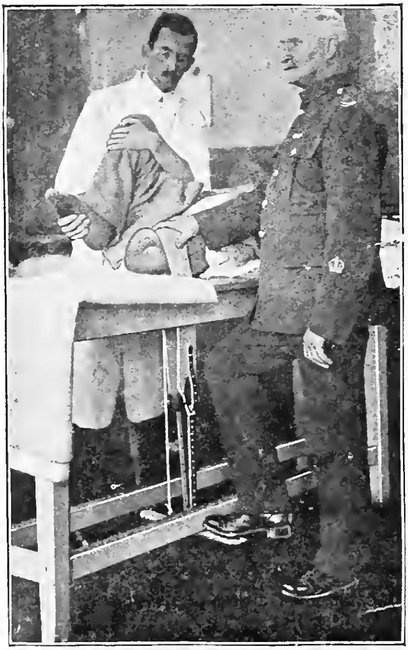

FIG. 57.—Table for forcing extension in amputation through the thigh with flexion contracture (from Mennell's *Massage*).

The patient should lie on a hard table, without pillows, with the pelvis straight; then, ignoring the stump, flex the healthy hip fully until the thigh is in contact with the abdomen. In this position lordosis is abolished and the full degree of flexion deformity can be estimated. Often the stump can be extended if abduction is permitted, or adducted if flexion is allowed, so that this must be guarded against, and the level of the anterior superior spines noted during the test. The tendency to this deformity is greatly diminished by the wearing of a temporary limb as soon as the stump has healed, or even before, because the flexed and abducted position of the hip in the sitting posture is an important factor in its

causation, and the temporary limb can only be stable if the patient keeps the hip well extended.

When flexion and abduction deformity of the hip is once established it must be overcome by daily stretching. The best method of carrying this out is that shown in Fig. 57. The patient lies on the table with the sound hip fully flexed, a strap passes over the stump and through two slots in the table to a pedal. The masseur extends the hip forcibly by pressure upon this pedal with his foot; he thus has both hands free to manipulate the stump and to overcome the abduction. Another method which is not quite so good is to hyperextend the hip, the patient lying upon his face.

Occasionally the contraction is so bad that no amount of stretching by hand will affect it. An open operation will then be necessary; unless this is done it will be impossible to fit a limb satisfactorily and to enable the patient to walk with security. The structures which require division are the tensor fasciæ femoris, sartorius, rectus femoris, muscles attached to the great trochanter and digital fossa, ilio-psoas, and often also the anterior and external part of the capsule of the hip joint. These can be divided through a free incision extending for about four inches downwards from the anterior superior spine.

When a thigh stump is very short it fails to get a secure hold in the thigh bucket and to control it. Practically the stump is too short unless it measures two inches on its inner side from the perineum. This is equivalent to about five inches of femur, measured from the tip of the great trochanter. These short stumps are almost always flexed and abducted, and the correction of this deformity is difficult because the leverage that can be exerted upon them is so small. Very often an ordinary thigh bucket cannot be fitted and it is necessary to keep the stump flexed and to enclose it entirely in a tilting table such as is used for fitting a hip-joint amputation.

It does not follow, however, that amputations high up in the thigh should be superseded by amputations through the hip joint. The additional shock involved in the latter amputation must always be remembered, and the high thigh amputation is consequently to be preferred as a primary amputation whenever it is possible. But when such a short amputation through the thigh has been carried out and the stump has become infected it may often be preferable to save the patient from a further prolonged illness by converting the amputation into one through the hip joint.

Amputation through the Hip Joint.—The Furneaux-Jordan operation is obsolete, the fleshy stump which results cannot hold and control a bucket; it must be folded up and enclosed in the tilting table; it is therefore only an embarrassment. The best amputation is

FIG. 58.

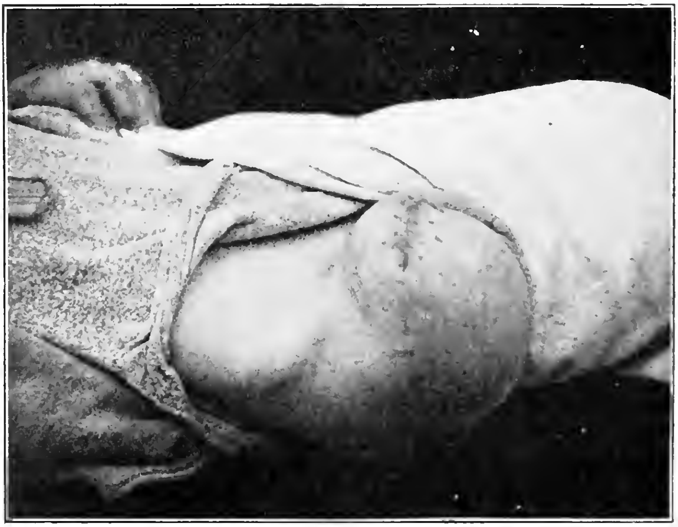

FIG. 59.

Very short thigh stump. On flexion the stump almost disappeared: it was insufficient to hold the bucket of an artificial limb, and a limb as for a hip joint amputation had to be fitted.

that with an anterior racket incision which is carried rather lower on the inner than on the outer side, so that the scar crosses the buttock well away from the perineum and from the tuberosity of the ischium. The flaps should be muscular if possible, so as to leave a good pad over the region of the acetabulum.

Amputations of the Upper Limb.

Whereas the function of an artificial leg is to transmit the body weight to the ground, that of an artificial arm is to act as a tool in gripping or supporting things whilst they are used and to transmit movement from the stump. In certain cases when the stump is long enough it may itself be useful without the addition of an artificial appliance. This is specially the case when some part of the hand remains. Whether the remaining portion is to be used as such or whether it is to serve as a support for an artificial appliance it is clear that in every case the only general rule that can be made as to the level of amputation is that every possible portion of the limb should be preserved so far as this is consistent with safety.

The presence of terminal scars or of adherent scars is of much less importance than in the lower limb; in fact, terminal scars are the best, because the pressure of the artificial appliance comes upon the circumference of the stump and not upon its extremity.

An artificial arm has to be fixed to the stump and to the trunk so that—

1. Traction upon it will not pull it off the stump. This resistance to traction is furnished (*a*) in amputations through the wrist or below it by a close fitting around the styloid processes of the radius and ulnar, (*b*) in amputations above this level by fitting around the condyles of the humerus when the stump is sufficiently long, and (*c*) by harness passing over the clavicle, acromion and spine of the scapula.

2. Upward pressure will not force the stump too far into the bucket. This is secured by (*a*) an accurate circumferential fit of the bucket around the forearm muscles below the elbow, and (*b*) a close fit beneath the folds of the axilla.

3. Torsion will not rotate the artificial arm upon the stump. In an amputation through the forearm or wrist rotation is resisted by a close fitting around the forearm, the transverse diameter of which is greater than its antero-posterior diameter, also by the fit of the steel or other attachment to the elbow joint. In amputation above the elbow there can be no resistance to rotation except that furnished by the arrangement of the shoulder harness.

Partial Amputation of the Hand.—When a finger or a part of the hand has been severely damaged the question whether or not an amputation should be carried out very commonly arises, and presents a problem which should never be settled without the fullest consideration. It may safely be said that in the early stages it is wrong to sacrifice a digit or part of a digit unless it is clear that the bones, joints and tendons are damaged to such an extent as to render recovery in function impossible, or unless gangrene or sepsis render it essential to get rid of the damaged part quickly. The final decision as to whether any part of the hand should be retained or sacrificed ought to be left until a late stage of treatment, when the function of the hand as a whole can be considered. I am here dealing then in the main with such late cases where the wound is completely or almost completely healed, where any fracture has had a fair chance of uniting, and where the final result of damage to the joints and tendons is evident.

In these cases two important questions have to be decided; first, when should a disabled finger or part of a finger be sacrificed? and secondly, when the decision to amputate has been arrived at, what amputation will leave the most useful hand?

In the first place in cases of general contraction of the hand the whole hand should never be sacrificed by amputation at the wrist. A hand of even very little functional utility is better than any artificial hand or appliance. This is specially to be remembered in those cases of functional spasm of the hand so often associated with wounds of the palm. I have seen several cases in which a hand, the joints, tendons, and even the intrinsic muscles of which were intact, has been sacrificed on account of pain and spasm. Even the amputation has sometimes failed to relieve the pain, and the patient desires the removal of yet another portion of the limb. Similarly the amputation of a painful finger is seldom followed by a relief of pain unless this is due to such a cause as fibrous ankylosis of one of the joints, in which case the pain might be relieved by operation upon the joint, or perhaps amputation of the finger may be justified by its loss of function and interference with the general utility of the hand. Wounds of the palm often produce pain by involvement of one of the digital nerves. Amputation of a finger does not relieve this pain, and the patient usually returns to hospital demanding a further amputation. On the other hand, section of the affected nerve at a point well above the wound will usually relieve the pain and restore functional use in the hand.

In cases of injury to the hand in which the joints, tendons, nerves and intrinsic muscles have been injured every case must be considered

on its own merits. The probable functional recovery of the injured parts, the possibility of restoration by operation, arthroplasty, tendon suture and transplantation, etc., and by prolonged treatment by massage, baths, electrical stimulation and re-education must be weighed before amputation is decided upon. Finally the occupation of the patient, the importance of strength, of dexterity, of appearance and of particular finger movements must be considered. It is only possible here to lay down certain general principles that will guide the judgment in individual cases.

The thumb should only be sacrificed when it is hopeless to save any part of it, even in a mutilated condition. A stiff thumb with all the joints ankylosed and all the long tendons lost is better than no thumb at all. If necessary, an arthroplasty may be carried out in the joints at a later stage (it is particularly indicated in the carpo-metacarpal joint), and suture or transplantation may restore the essential functions of the long tendons. When, owing to scarring or loss of substance, suture of the long extensors or their replacement by transplantation is impossible a fair degree of utility may be secured by arthrodesing the interphalangeal or metacarpo-phalangeal joint. The stump left by amputation at the metacarpo-phalangeal joint is a very useful one if power of opposition remains. Joyce has recently described a case in which a finger from the opposite hand was transplanted to replace all three bones in the thumb, the long tendons being sutured and the intrinsic muscles which had escaped being fixed to the new digit. An American colleague tells me of a case in which a toe was used to replace the phalanges. The possibility of such surgical successes indicates the necessity for preserving as much as possible of the proximal part of the thumb and its use in cases of the most severe injury.

It is often advisable to sacrifice an individual finger when its metacarpal-phalangeal joint or the first interphalangeal joint has been destroyed or is ankylosed, flail or badly out of alignment. The points to be considered are—

1. Is the condition capable of correction by operative measures?
2. If not, is the disabled finger interfering with the function of its fellows?

In the metacarpo-phalangeal joint arthroplasty has a fair prospect of success if the tendons are intact. In the interphalangeal joints it is not likely to succeed, particularly as at this level the tendons will seldom have escaped serious injury. Injury to the long tendons at the level of the metacarpo-phalangeal joint is serious; operation seldom results in good function except in the case of clean division

of the extensor. Practically, in many cases a finger, the flexor tendons of which have been divided, will require amputation at the first interphalangeal joint. It is very rare to get good functional movement in the interphalangeal joints restored.

Destruction of the interossei of one space may produce a lateral deviation of the finger which interferes to such an extent with the use of the hand as to render amputation advisable. In a similar way a mal-united fracture or ununited fracture of a metacarpal bone may necessitate the sacrifice of a finger because, although some of its own movements remain, it interferes with the general utility of the hand by impeding the use of the undamaged fingers. Operation for the correction of faulty alignment in the metacarpal bones by osteotomy and grafting in these bones have not so far been extensively tried. The cases in which these are possible are few because these fractures of the metacarpals are so often associated with serious injury of the tendons which in themselves indicate the advisability of amputation.

It is scarcely necessary to speak of the methods of amputation through the phalanges or interphalangeal joints. When possible it is advisable to use a long flap and so leave the scar on the dorsal surface. The tendons should be sutured across the ends of the bone. and it is most important to cut short the digital nerves, as a painful stump is not at all uncommon. When amputation at the metacarpo-phalangeal joint or at a higher level has to be carried out the method must depend upon the nature of the injury. As a rule a stronger hand is left by amputation through the joint, but if the metacarpal bone has been fractured it will usually be better to remove its distal end. When this is done in the little finger the tendon of the abductor minimi digiti should be sutured to the side of the extensor tendon of the ring finger so that it may act as an abductor of that finger.

When more than one finger has to be sacrificed together with parts of the metacarpal bones, it may be better to abandon altogether the idea of leaving anything which resembles a natural hand, aiming rather at the preservation of a member which resembles a lobster claw. The power possessed by two digits which have good mobility and which can be opposed tightly to each other is very great. This is seen in the congenital lobster-claw deformity of the hand, and this deformity has been imitated in some cases of severe injury of the hand by the preservation of the thumb and ring finger, the index and middle fingers being sacrificed, together with a large part of their metacarpal bones.

In still more extensive injuries to the hand the preservation of a single digit is useful, provided that it is mobile. An attachment can be fitted to which the digit can be opposed, and a grip thus secured

which is more useful and more under control than that of an entirely artificial appliance.

Fig. 60.

Fig. 61.
Amputation through the wrist joint; Fig. 60 in the pronated position, Fig. 61 in the supinated position.

When no digit remains it may be possible to leave a mobile stump consisting of some part of the carpus and metacarpus, which retains

the attachment of the extensors and flexors of the wrist; this mobile extremity to the stump may be of service itself, or it may be possible to use it to actuate the fingers of an artificial hand.

Amputations at the Wrist.—Amputation through the wrist joint is not a favourite one with limb-makers, but nevertheless it is a good one. The preservation of the inferior radio-ulnar joint leaves pronation and supination full, and the fact that the styloid processes remain enables us to fit the bucket of the artificial appliance around them and to hold it on securely. It is a good thing to remove the prominent tips of these processes so as to leave a flat end to the stump, but it is a mistake to amputate above the wrist, as this leaves the movements of pronation and supination much less strong and full. Limb-makers object to this amputation through the wrist because it is difficult to fit and because it necessitates making the artificial limb a little longer than the natural one. These are small points compared with the additional functional utility.

Amputations through the Forearm.—In amputations through the forearm the only rule is to preserve all that is possible; every inch left gives additional use, and a stump that comprises more than half the length of the forearm will probably preserve a certain amount of pronation and supination movement.

The operation of cinematisation of stumps has recently been advocated, more particularly by Putti in Italy. The object is to leave one or more mobile parts at the extremity of the stump and to fix to these some of the divided muscles. These muscles are then trained until they become strong, and by attaching the parts to which they are fixed to cords an artificial hand can be given natural movements. For example, in an amputation through the lower part of the forearm the tendons of the flexor muscles may be collected into a bunch and skin sutured around them so that a mobile projection is formed. A metal ring covered with vulcanised rubber is clamped around this projection and to this a cord is attached. Contraction of the flexor muscles will pull this ring up the limb, and the resultant pull on the cord can be made to close the fingers of an artificial hand. In a similar way the extensor muscles can be collected and the resultant pull made to open the fingers of the hand. The forearm is the most suitable part for the trial of this method. It is a method which is still on its trial, and one that should never be carried out by a surgeon unless he has the facilities for getting the artificial hand made under his own supervision. But the fact that such procedures are possible is a strong reason for the preservation not only of bone, but also of muscles in an amputation through the forearm.

In amputations in the upper third of the forearm it is difficult to fit the bucket of the artificial limb. The reason for this is that the antero-posterior diameter of the top of the forearm increases when the elbow is flexed, so that a bucket which is a tight fit with the elbow

Fig. 62.

Fig 63.

Very short forearm stump in the extended and flexed positions. In flexion the raising of the muscles attached to the condyles of the humerus will push off the bucket of the artificial arm.

extended is too tight when the joint is flexed, or if the fit is correct with the elbow flexed, it is too loose when the joint is extended. The usual result is that the artificial limb tends to be pushed off when the elbow is flexed. This difficulty arises when the stump of the ulna

is less than about four inches: when this bone is less than two inches long the stump disappears altogether in the flexed position, and fitting is impossible.

With a stump containing from two to four inches of ulna it is best to fit the artificial arm by Williams' method. The arm is attached by a close-fitting leather collar which laces around the condyles of the humerus, the forearm bucket is fixed to the margins of this in a position of slight flexion of the elbow; the elbow can be further flexed to a right angle or beyond, but it cannot be completely extended. This permanent slight flexion of the elbow is an essential part of this method of attachment. The artificial arm thus fitted is light and very useful. Williams himself has worked with such an arm for many years in a coal pit, his stump being a short one below the elbow. It has been suggested that in these cases the muscles attached to the condyles of the humerus should be excised and the obstacle to fitting thus removed. This may be an assistance in some cases. In my opinion, however, it will rarely be necessary if the above method of fitting is used. It will not enable a below-elbow fitting to be carried out in cases in which the ulna is only two inches long.

When the forearm stump is too short to allow of the fitting of any artificial forearm bucket it is necessary to enclose the whole of the end of the stump in a leather bucket and to fit an artificial elbow joint. Some surgeons consider that when this is necessary it is better to amputate above the elbow. In my opinion this is wrong, for two reasons—

1. The presence of the condyles of the humerus enables us to fit closely around them, and thus to secure the artificial arm against traction and against twisting.

2. It is quite possible that in the future a method will be found of utilising the small piece of forearm remaining, either by cinematisation of the stump or by an improved mechanical arm. For this reason this piece should be preserved even if at present it appears to be only an embarrassment.

Amputations through the Elbow Joint.—Amputations through the elbow joint are unpopular with the limb-makers, and some surgeons advise that they should not be carried out. In my opinion this is wrong. The reasons for condemning the operation are that the end of the stump is enlarged and consequently a leather bucket has to be made to lace around it, the limb being a little clumsier and more difficult to fit than the ordinary artificial arm for above-elbow amputations, and rather more trouble for the patient to put on and off. On the other hand, if the condyles of the humerus remain, a good hold can be secured by fitting around them so that the arm does not pull

off easily and is not rotated. These counterbalance any difficulty in fitting and render the amputation a good one. The chief reason against amputation through the elbow is a surgical one, viz. that it requires a large flap which is seldom available, and that it can only be carried out when the lower end of the humerus is uninjured. When it is possible to amputate through the elbow, but not below, this operation should be carried out.

Amputations through the Arm.—In amputations above the elbow it is obvious that every inch of bone preserved is valuable. No other comment is necessary except to remark that in this region the large nerves are specially subject to the development of painful neuromata, so that they should always be treated by crushing, ligature, and shortening in the way described below.

Amputations through the Shoulder.—In order that an amputation stump in the arm may be able to transmit movement to the artificial limb the bone in it must project well below the axillary folds. If the stump from the anterior axillary fold is less than two inches it will possess little useful movement; if its length is less than an inch it will be practically impossible to fit an arm with a mobile shoulder. These facts do not in any way modify the method of amputating. Everything possible should be preserved, whether it appears that it will be useful or not; patients with very short arm stumps and those with amputations through the shoulder joint very seldom wear their artificial arms except for show. The presence of the upper end of the humerus preserves symmetry of the shoulders, and this piece of bone should never be sacrificed unnecessarily.

Painful Amputation Stumps.

Many amputation stumps are painful. Most often this is due to pain or tenderness in the divided nerves. A painful stump should be carefully investigated and the exact site of the pain localised. In the majority of cases a definite tenderness will be found to exist over the enlarged ends of one or more of the main nerves. In others the tenderness is more diffused, in others, again, the whole stump is painful. When a nerve is divided the axis cylinders grow out from the central end. If there is no peripheral end for them to grow into, they coil about in the immediate neighbourhood, forming a neuroma. They do not, however, confine themselves to this, but they may spread also into the surrounding tissues, and be identifiable at a considerable distance from the cut end of the nerve. Every cut nerve must form a neuroma; the object of the surgeon should be to make sure that this neuroma is confined within limits, and that it is situated so that it is not liable to pressure.

The best method of limiting the neuroma is the following. The nerve should be crushed in a pair of pressure forceps or in an appendix clamp, so that the axis cylinders are severed without division of the sheath of the nerve. A catgut ligature is then passed through the sheath at the point crushed, wound completely round the nerve and tied. The nerve is then divided distal to this ligature. By this means the new axis cylinders are confined within the sheath and prevented from wandering in the surrounding tissues. In performing an amputation every large nerve should be treated in this way and at the same time shortened so that it does not lie too near the end of the stump.

When a stump is painful it should be carefully palpated. It will most often be found that some one or more of the larger nerve ends is enlarged and tender on pressure. Sometimes in addition to this, or instead of it, it will be found that there is a considerable area around the end of the nerve pressure over which produces discomfort or pain, perhaps with sensations referred to the distribution of the nerve. This is due to axis cylinders which have grown out from the nerve and wandered into the surrounding tissue. Sometimes there is no neuroma palpable in the region that is painful. The condition may then be due to one of the smaller nerves, for example to one of the cutaneous nerves of the part, or it may not be due to a nerve at all; it may be due to a painful thickening around a ligature or to some inflammatory trouble in the bone. Therefore, in a painful stump, the first thing to investigate is the condition of the larger nerves, next the smaller nerves, next the other tissues and bone; for the last-named purpose an X-ray is essential.

As has already been pointed out, the formation of a neuroma upon the cut end of a nerve is a normal process, and these neuromata are always sensitive, at least for a considerable time. It is quite unnecessary to interfere with them surgically unless they interfere with the wearing of the artificial limb or unless they produce pain spontaneously.

The treatment of a painful stump must be surgical. If there is a painful neuroma it must be removed, the nerve being crushed and ligatured in the way already described. If there is a localised painful part of the scar, such as is due to the inclusion in it of the cut end of a small nerve, this part of the scar must be exsected. If there is a painful inflammatory nodule around a ligature, this must be removed. If there is necrosis of the bone or a chronic osteitis, this must be treated by the removal of the sequestrum or by incision into the bone, or perhaps by removing a small portion of the end of the bone.

A neuroma may be painful for several different reasons. Most often the pain is due to adhesion of the neuroma to a scar. Sometimes it is due to wandering axons in the surrounding tissue, sometimes it is due to the nerve being divided at a level which subjects it to pressure or friction. In some cases, however, the pain is due to a neuritis, of the same nature as that which produces causalgia, and in these cases it may be very difficult to cure even when considerable further sections of the nerve are removed.

An occasional complication of a painful stump is a constant

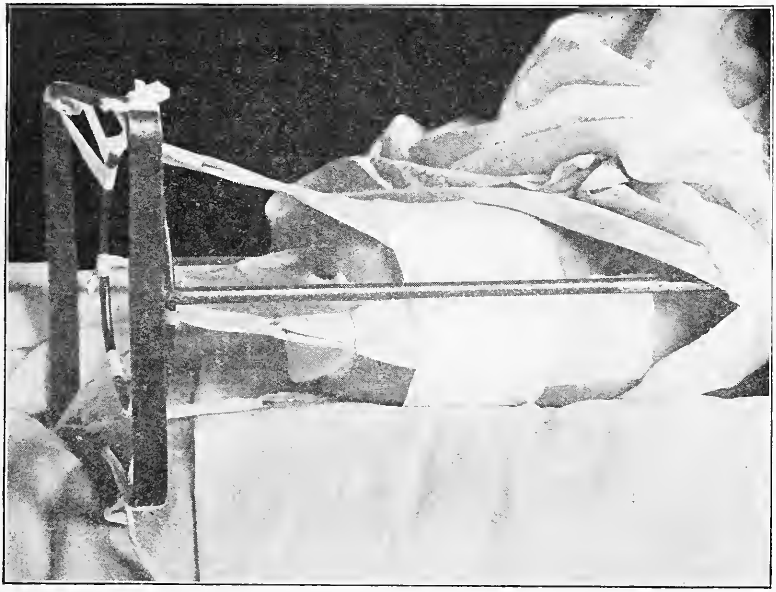

Fig. 64.—Method of applying extension to the flaps of an unclosed amputation stump. A Thomas's ring surrounds the top of the thigh; the lateral bars from this end in a large square metal frame. Four extension straps (in this case of adhesive strapping) are applied to the skin and fastened to a metal ring. The extension is obtained by securing this ring to the square metal frame.

twitching or shivering of the stump. In these cases it will nearly always be found that there is a painful nerve, and that the pain is referred to the distribution of that nerve. This nerve should be cut short, after crushing and ligature, and the stump should afterwards be immobilised in plaster of Paris for a period of six weeks. In some cases in which the pain and shivering have recurred after the removal of the ends of the affected nerves, I have succeeded in curing this condition by re-exploring, crushing the affected nerve and another of the main nerves, dividing them and anastomosing their ends.

The Treatment of Unhealed Stumps.

Many of the amputations of war surgery have to be carried out under conditions which necessarily preclude the possibility of primary union. So much is this so that very often no attempt is made to suture the wound, the amputation either being carried out by the guillotine method, or, more often, flaps being cut, but turned back and left unsutured. These operations serve two most important purposes, they preserve as much as possible of the limb and they secure good drainage in what is almost certain to be a septic wound. If they are properly treated they will give an excellent result.

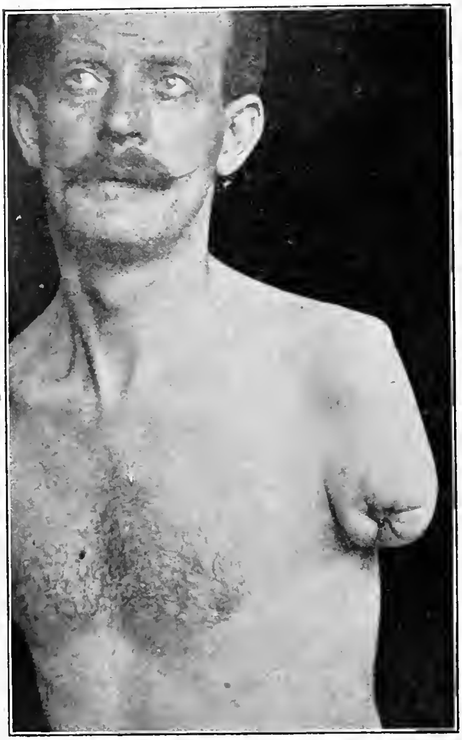

Fig. 65.—The final result of a guillotine amputation of the arm which was treated by the application of extension to the skin. There was a small adherent terminal scar which caused no trouble.

When such an amputation remains aseptic, a delayed suture can be carried out at the base. If the flap is sufficient no further trimming is necessary, if it is insufficient a short piece of bone must be removed.

When the amputation becomes septic, early suture is impossible, and as necrosis of the end of the bone is almost certain to occur, secondary suture in the early stages is also impracticable. The first essential in the after treatment is to prevent the retraction of the skin around the end of the stump and of the flaps, which will certainly occur if no steps are taken to prevent it, and which may necessitate shortening of the stump by reamputation. The best method of preventing retraction of the skin is by extension upon a suitable splint. The method for the thigh is illustrated in Fig. 64. A Thomas's ring is fitted around the top of the thigh. The side bars of this end in a square frame, which projects beyond the end of the stump. Four

extensions of strapping or of gauze fixed with Sinclair's glue to the anterior, posterior and lateral aspects of the stump are tied to a ring which fits inside this square frame. The extension is then kept up by tying the ring to the square frame. The whole of the end of the stump is left exposed and the dressing can be changed without interfering with the extension.

FIG. 66.—The result of a guillotine amputation of the thigh; there was a large adherent terminal scar which was stretched by the circumferential pull of the artificial limb bucket.

The next question that arises is the time at which reamputation is advisable. Early reamputation is a mistake, it is extremely likely to be followed by fresh suppuration, necessitating yet another operation. If the treatment is well managed the second operation should be the last. The time at which this second operation should be carried out is settled by two points, (1) the presence of necrosis and the separation of any sequestra, and (2) the condition of the surrounding tissues.

FIG. 67.—Skiagraph of a thigh stump with ring sequestrum separated and enclosed by new periosteal bone.

If possible it is as well to keep any bare bone in the end of the stump in view until the part which necroses has separated. If this is impossible the separation of sequestra must be judged by X-ray appearances and by the time usually taken for sequestra to separate in the bone affected. In the smaller bones this is about two months, in the femur it may be three months, in the tibia it may be even longer. If

it is considered advisable to keep every possible inch of the stump the second operation should be postponed until the sequestra have separated. If, however, it is thought advisable to sacrifice an additional length of bone, because, for example, there is insufficient skin to cover the end, or because the original amputation is at a bad level, then an earlier operation may be performed provided that the other conditions are favourable.

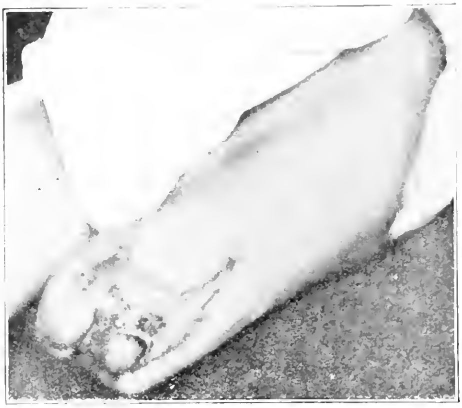

Fig. 68.—Unhealed amputation stump with a large ulcerated area in the centre of an extensive scar. The limb was reamputated, 2 inches of bone being removed, a long internal flap was cut, all the skin down to the margin of the scar being utilised.

The unhealed area at the end of a stump is necessarily infected. It can, however, be avoided during a reamputation, or it can be treated by a preliminary sterilisation by cauterisation with carbolic acid. The presence of such an area, therefore, does not prohibit the performance of a reamputation. It is otherwise with any septic infection of the skin, subcutaneous or other tissues further up the stump; these must necessarily be cut through in carrying out the reamputation, and if they are infected the new wound will be infected. The sign that infection is present in them is the presence of œdema. So long as the stump is œdematous reamputation or trimming operations are unsafe; the most that may be done at this stage is the removal of a sequestrum by slightly enlarging a sinus.

Fig. 69.—The result of reamputation of the stump shown in Fig. 68, photographed three weeks after the operation. The patient was able to walk upon a plaster peg leg one week later.

Provided, then, that œdema has disappeared from the stump, a second and final operation may be undertaken. The nature of this will differ according to the conditions present.

1. When the amputation is at a satisfactory level, when there is sufficient sound skin to cover the end of the bone, and when any sequestra are separated, a secondary suture may be performed. The sequestra are removed, with as little disturbance as possible, the edges of the epithelium trimmed away and the skin undercut, the wound treated with BIPP or other antiseptic, and the skin sutured with a small drain.

2. When the skin is insufficient to cover the stump, it is justifiable to reamputate before the sequestra have separated, provided that it is necessary to remove enough bone to make a fresh division of the shaft above the level of the infected area in the bone. The skin flaps should be cut by keeping close to the margin of the scar, the deep tissues should then be divided right down to the bone at the level of the proposed new section, and the bone divided at that level.

Fig. 70.—Skiagraph of the stump shown in Fig. 68 before reamputation, showing portions of a ring sequestrum enclosed by new bone.

3. If it is not desired to remove so much bone, then we must wait until the sequestra have separated. The skin must be cut as in the last case, the sequestra removed, the bone cleaned up and treated with BIPP as in an operation upon a bone sinus, and the skin sutured with drainage.

4. If the level of the amputation is a bad one and it is desirable to reamputate at a higher level, then a clean reamputation may be performed at the higher level, as soon as the œdema has disappeared, and the skin is in good condition at the new level. For example, in a septic amputation through the lower end of the tibia we know that the final result will be unsatisfactory. As soon as the œdema has gone, we may reamputate at the junction of the middle and lower thirds of the leg.

The presence of adherent scars upon a stump is sometimes

FIG. 71.—Skiagraph of an amputation stump with a sinus. There was a terminal sequestrum partly enclosed by new bone.

considered to be a reason for reamputation. This is only seldom so. A stump in a good position should never be shortened for this reason until after an artificial limb has been tried, and it should then only be carried out upon the advice of a surgeon who is accustomed to the fitting of artificial limbs. It is not at all infrequent to find that a reamputation has been done because the artificial limb has given trouble, and to discover that the real fault has been with the limb, which no longer fits because of shrinking of the stump.

In carrying out a reamputation in the presence of an unhealed area or sinus, the whole of the extremity of the stump should be looked upon as an infected area. The ulcer may be carbolised at the beginning of the operation, and it and the scar should not be touched with any instrument or swab which is afterwards allowed to touch the newly cut tissues. Only by this precaution can the new wound be kept aseptic.

FIG. 72.—Skiagraph of a thigh stump, showing a small lateral sequestrum enclosed by new bone.

Many amputations when they first come under the care of the orthopædic surgeon are healed except for a small sinus. These must be treated upon the same general principles as are other sinuses. The cause of the sinus is the presence of a foreign body, a

piece of necrosed bone, of metal or of clothing or a non-absorbable ligature, or else the presence of a cavity with walls of bone or of dense scar tissue which cannot collapse.

The condition of the bone must be investigated. If it is sound a simple curetting of the sinus or its excision will suffice. If necrosis is present it must be treated, either upon the lines laid down in Chapter II, or else by a reamputation as suggested above.

Fig. 73.

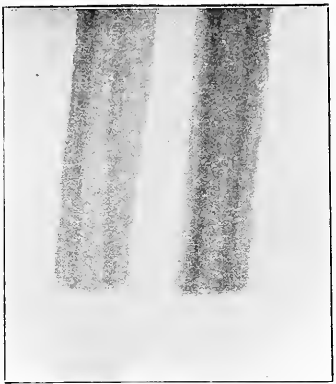

Fig. 74.

Skiagraphs of a forearm stump; the ends of the bones were rough and irregular as the result of a chronic osteitis after the separation of sequestra. Fig. 74 shows the result of reamputation with the removal of small portions of bone.

Shrinking of Stumps.

Many of the muscles of a stump cease to function because of the removal of the distal joint. These muscles tend to shrink progressively. If the shrinking were due entirely to this cause it would be sufficient to wait a definite period before fitting the artificial limb, and it would then be possible to fit a limb which would never require alteration. This is, however, not so. The shrinking is to a large extent the result of pressure upon the stump, so that when a limb is fitted the part upon which the bucket presses tends to get progressively smaller for a considerable period, often for a year. This shrinking soon affects the fit of the bucket. To a certain extent the alteration in the stump can be accommodated by lining the bucket with paraffined leather, or by wearing additional stump socks, or in the case of a leather bucket by lacing this up more tightly. But the extent to which this is possible is limited, because the shrinking is only of the soft parts, and the bones, therefore, become more prominent. This is particularly so in stumps below the knee, in which the head of the fibula and tuberosities of the tibia become much

more prominent and require deeper concavities excavated for them in the bucket. Therefore, in most cases sooner or later an entirely new bucket must be made. Sometimes even a third or fourth bucket may be required before the stump attains its permanent shape.

The faulty fit of the bucket of an artificial limb due to shrinking

FIG. 75.—Skiagraph of a short thigh-stump with a diffuse formation of new bone around the extremity of the femur.

of the stump may become evident through the appearance of pain or discomfort in the stump. For example, in an amputation below the knee a loose bucket produces friction on the head of the fibula and an inflamed bursa makes its appearance there. It is useless to excise such a bursa unless the bucket is refitted immediately after to prevent the recurrence of the friction. Exostoses are not uncommon upon the cut end of the bone, particularly in amputations through the

thigh. These are of two sorts, (1) a diffuse exostosis around the end of the bone, the result of chronic periostitis from sepsis, and (2) a backwardly directed spur of bone formed in a muscle attachment usually arising from the linea aspera. These exostoses seldom give trouble when the artificial limb is first fitted, the padding supplied by the muscles being sufficient to prevent any uncomfortable pressure. The only exception to this is that occasionally a nerve end may lie over or be attached to the spur, and severe pain may result from pressure from the latter upon the nerve. When the stump has shrunk, however, the spur of bone may be no longer adequately protected; it may then become painful. If difficulty is found in refitting because of the presence of such a spur, it should be chiselled off and removed through a small incision.

Fig. 76.—Skiagraph of a thigh stump with a spur on the inner side springing from the linea aspera.

Very often the shrinking of the stump gives rise to a very defective gait, and if the cause is not appreciated it may be thought that the artificial limb is badly designed or badly made. For example, when a thigh stump shrinks the bucket becomes too large and the stump passes too far down into it, so that the tuberosity of the ischium no longer rests upon its proper shelf but passes inside the bucket. One result is to make the limb too short, another is to make the inner edge of the bucket rest against the perineum. Pressure upon the perineum is uncomfortable, and to avoid it the patient abducts the stump, carrying the limb away from his side, walking becoming unsightly and irksome. Whenever an artificial limb which has been at first comfortable and efficient ceases to be so, or whenever the stump within it becomes painful, the first step should be to examine the fit of the bucket and to find out whether, owing to shrinking of the stump, this is no longer accurate.

Temporary Artificial Limbs.

When a patient who has suffered an amputation of the lower limb waits for many months whilst the stump is healing and consolidating before he is fitted with an artificial limb, this eventual fitting becomes much more difficult. In the first place he has become used to walking with crutches and is perhaps so adept at their use that he prefers the rapid progress that he can make by swinging along upon them to the. at first, rather laborious progress upon an artificial leg. Then the muscles of the stump are atrophied and often the stump itself has become contracted. In particular a short stump in the thigh is apt to become flexed and abducted at the hip as the result of the position assumed in sitting. These difficulties indicate the importance of securing healing of the amputation stump as rapidly as possible and of encouraging the use of a temporary artificial limb at the earliest possible moment. Another reason for advocating the wearing of a temporary limb is that by exerting the same pressure upon the stump as does the bucket of the permanent limb, it assists in promoting rapid shrinking of the stump, so that it is more likely to have assumed its permanent shape before the final limb is fitted, in this way lessening the chance that the bucket of this limb will require alteration.

Against these arguments in favour of the use of temporary limbs has been urged that if a temporary limb of the peg-leg type is worn the patient will get into the habit of walking with an unnatural gait, due to the fact that the peg leg has a stiff knee, and that it will be difficult or impossible to induce him to correct this habit when the permanent limb is fitted. This allegation is not true; patients who have worn peg legs for long periods are taught to use full mobile legs with perfect ease, in fact they learn to walk well more quickly than do those who have worn no limb at all. It is true that a certain number of men who have worn a peg leg will never take kindly to the full limb, they find the latter heavy and difficult to use after the peg; these are particularly men with short thigh stumps; they would find the full limb difficult in any case, and if they prefer to wear a peg leg permanently, no one can deny them the right to do so.

It is now generally agreed that it is important to secure healing of a stump as rapidly as possible and to fit a temporary leg at least as soon as the wound has healed. The period of walking with crutches should be reduced to the shortest possible. A scientific treatment of unhealed stumps upon the lines already indicated is the first step, the second is the fitting of a simple peg leg as soon as healing has been secured.

A temporary limb takes its bearing in exactly the same way as

does the permanent limb, *i.e.* for a thigh amputation the main bearing is upon the tuberosity of the ischium, with a subsidiary circumferential fitting upon the whole stump. For an amputation below the knee the bearing should be chiefly upon the head of the tibia, but there should again be a close fitting around the whole stump. For Syme's amputation the main bearing should be upon the end of the stump, but as at an early stage this may not stand pressure very well there should be also a close fitting around the whole leg up to the head of the tibia, as for the ordinary below-knee stump.

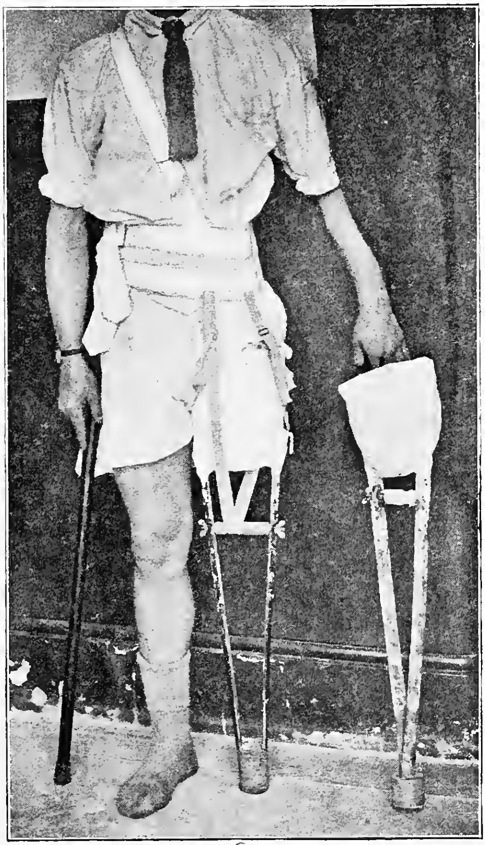

Fig. 77.—Plaster of Paris peg leg. The crutch stick is specially made, having a base block $2\frac{1}{2}$ inches wide.

The simplest method of fitting a temporary limb as well as the most satisfactory is by making a bucket of plaster-of-Paris bandages moulded around the stump, and attaching to this the peg leg made of a framework of wood. The following is the actual method for a thigh amputation.

The framework of wood is made by cutting down an ordinary Wantage crutch. The handle is fixed at a sufficiently low level to be clear of the end of the stump, and is freed so that it becomes a roller, a circular groove being cut in it. To the outer bar of the crutch is attached a hook of thick galvanised iron wire. The patient lies upon his back with the buttocks raised upon a sand-bag, the stump is then enclosed in a tube of stockinette, which is drawn up over the groin and buttock tightly; it extends upwards to the fold of the groin in front, to above the level of the tuberosity of the ischium behind. When this preliminary fitting is finished a plaster-of-Paris

bandage is applied tightly over the stockinette. the whole stump being enclosed up to the level of the tuberosity of the ischium. the plaster is moulded particularly against the tuberosity of the ischium, until it is just set, the stump being held fully extended and parallel to the other limb. Then the crutch is held in place so that it lies parallel with the other leg and so that the lower end is just level with the heel of the boot, and a second plaster bandage

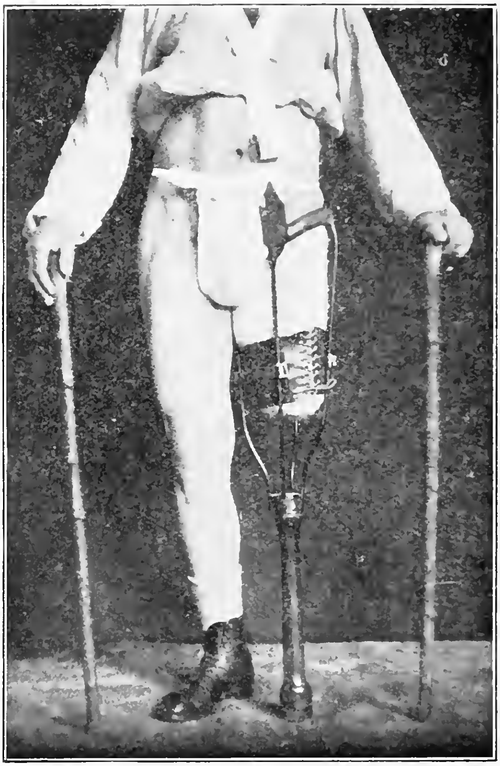

Fig. 78.—Peg leg made on the Thomas's splint pattern.

applied around the bucket and top of the crutch completes the limb. When the plaster has had time to dry thoroughly the leg can be worn. It is held on by a webbing strap which passes under the roller on the crutch and is attached to a broad waist-belt in front and behind, and by a second webbing strap which attaches the hook on the outer side to the belt. The latter can be kept from slipping down by shoulder-straps.

The advantage of this limb is that it is simply made, and that it

fits the stump accurately. If the latter shrinks so that the bucket is too loose a new one can be made in a few minutes. Very little experience is required to fit the bucket.

For amputations below the knee the bucket is made in exactly the same way, and the peg is completed by incorporating in the plaster a

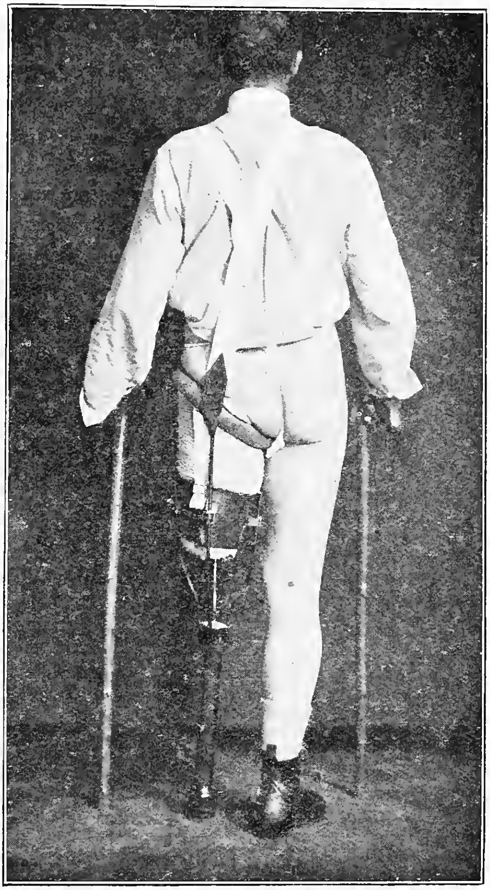

FIG. 79.—Peg leg made on the Thomas's splint pattern.

number of thick strips of wood to which a round block of wood is fixed below. When the stump is long this leg can be kept on by attaching it by two lateral straps to a broad thigh-band of webbing which encloses the thigh immediately above the condyles. When the stump is short it may be necessary to incorporate in the bucket lateral steels with joints at the knee and with a light thigh corset of leather to lace up. For Syme's amputation the same method as

for a long leg stump may be used, but as the end of the stump is bulbous the limb will not be removable. It may be possible thus to fit up a Syme's amputation as early as one month after the amputation, the patient taking practically his whole weight upon the end of the stump.

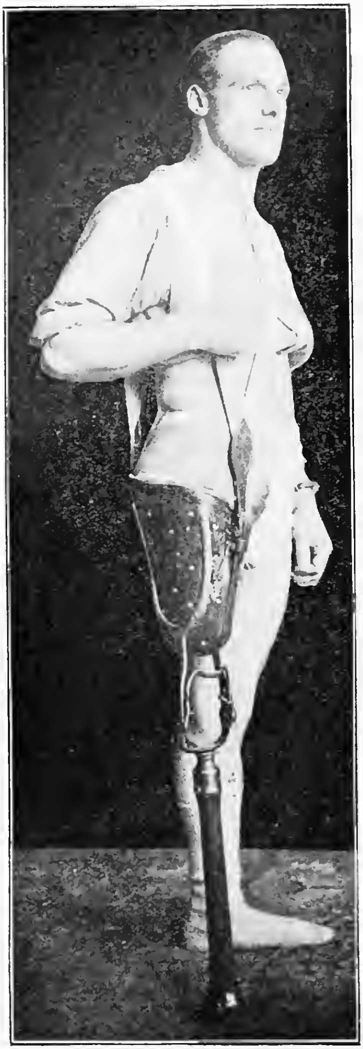

FIG. 80.—Peg leg of leather and steel with locking knee. The bucket is made upon a plaster-of-Paris cast of the stump.

A still simpler temporary limb is that made with an ordinary metal Thomas's ring, taking its bearing from the tuberosity of the ischium, and with two or four vertical bars to which the wooden peg is fitted below. This can be used for stumps which are still unhealed. Its chief disadvantage is that it does not exert circumferential pressure upon the stump, and so does not help shrinking. The addition of a bucket of leather, webbing or thin wood or fibre inside the ring meets this objection to some extent, but, unless firm leather moulded upon the stump is used, it is not possible by this means to exert a really uniform pressure. A similar peg leg has been designed in which the ring and vertical bars are made of wood, and the inside bucket of three-ply wood. The use of wood for the ring does not appear to present any advantages; it is weaker, and it introduces the difficulty of carving. These peg legs made upon the Thomas ring pattern have the advantage of being standardisable.

Very simple and useful peg legs are made of vulcanised fibre by the various War Supply Depots. A sheet of the fibre is wrapped around the stump so as to form a conical bucket, and to the lower end of this a wooden peg is fixed. Such a conical bucket cannot fit very accurately. It is well lined upon the inside with soft felt and the fit thus

improved, but even then the weight comes chiefly upon a small ring at the top of the bucket, and the even pressure upon the surface of the stump that is necessary to produce shrinking cannot be obtained. However, these temporary limbs are simple, and can be made by those who have no knowledge of anatomy or of plaster work; they are therefore of great service.

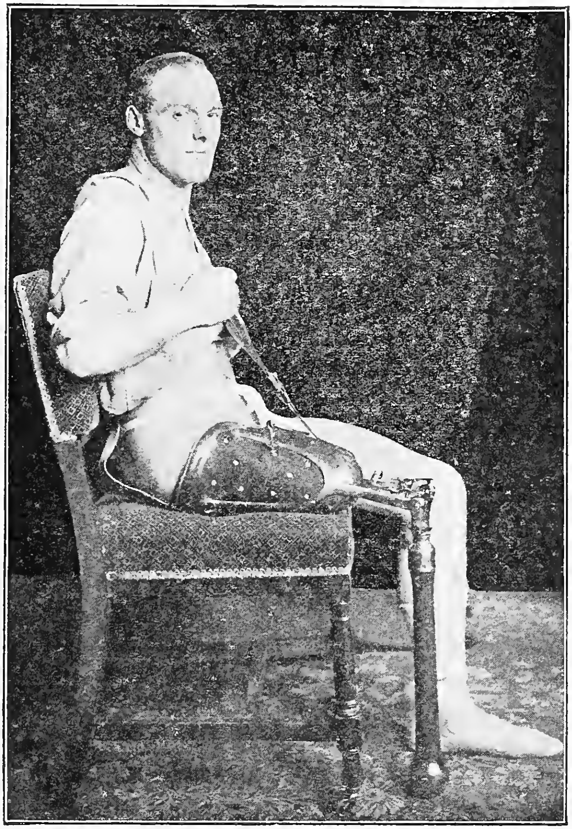

FIG. 81.—Peg leg of leather and steel with locking knee. The bucket is made upon a plaster-of-Paris cast of the stump.

A more elaborate peg leg can be made of leather and steel where workshop assistance is available. A plaster-of-Paris cast of the stump is first taken, the positive being trimmed down a little on the postero-internal aspect, below the region of the tuberosity of the ischium. On to this a leather bucket is made, the front of the bucket being split and laced, so that it can be taken in a little as the stump shrinks. Side steels from the bucket end in a stirrup-shaped knee-piece, with a locking joint, the peg being inserted into this below the knee.

CHAPTER XII

REPAIR IN THE UPPER LIMB

Extensive Destruction of Tissues in the Shoulder Region.

Fig. 82.—Extensive scar over the scapula, involving a separation of a considerable portion of the trapezius from its attachment to the scapular spine.

Over the clavicle, acromion and scapula extensive wounds involving considerable loss of skin, muscle and bone are not uncommon; they result in the production of large adherent scars which heal very slowly and imperfectly, considerable ulcers often remaining in the centre of the scar and refusing to close over entirely. Even when these wounds have completely healed the friction of the clothes and the tension of the scar due to the weight of the arm may be sufficient to cause fresh ulceration, so that the mere presence of the large thin adherent scar is in itself objectionable. But in addition, in these cases, there is often a loss of continuity of the bony arch constituted by the clavicle, acromion and scapula, and of the support given to this arch by the attachments of the trapezius muscle to its upper border. The loss of this support throws the whole strain of the weight of the arm upon the scar. It is comparatively simple to excise these scars and to cover in the area

left with healthy skin, replacing fragments of bone in their proper position and suturing the muscle attachments, whenever this is possible. The skin over the front and back of the chest is abundant and elastic, and flaps can usually be turned upwards in front and at the back to cover any raw area; our aim should be to produce linear scars and so to suture the trapezius as to give support from above to the shoulder girdle. When the operation wounds have healed the scars should be worked free from the deep parts by a little gentle massage. Figs. 82, 83 and 42 to 45 show the possibility of covering considerable areas in the shoulder region by these methods.

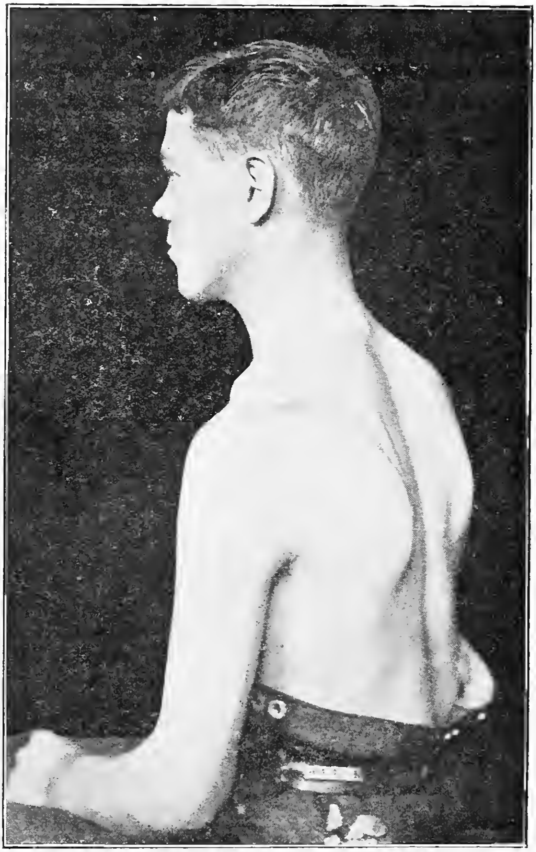

Fig. 83.—The result of excision of the scar with bevelling down of the spine of the scapula and reattachment of the trapezius.

Flail Shoulder Joint.

Injuries which have destroyed the head of the humerus, particularly those in which an early excision of the comminuted fragments has been carried out, leave a loose flail condition of the shoulder joint which renders the entire arm useless, in spite of the fact that the elbow, forearm and hand are in every way normal. The complete loss of the deltoid muscle, either by destruction or by paraylsis, results in almost as much disability. A flail condition of the shoulder may, therefore, be due either to loss of bone, or to destruction of the muscle, or to paralysis; not infrequently there is a combination of these, as extensive comminution of the humerus is liable to be

accompanied by injury to the circumflex nerve, or destruction of the deltoid.

It is essential that some sort of repair should be carried out which will give such stability to the shoulder as will enable the elbow, forearm and hand to be used. Several possible methods may be used, the actual method indicated in each case depending upon the special conditions present.

1. When the deltoid is present and active, the glenoid fossa intact and a short portion (not more than two inches) of the humerus missing, the arm should be supported upon an abduction splint, abducted 90° and flexed slightly forwards. This position should be

FIG. 84.—Extensive destruction of tissue over the shoulder. The deltoid was destroyed, the humerus had been fractured but had united, the centre of the scar remained ulcerated.

maintained day and night and never relaxed, and electrical treatment of the deltoid carried out. In time the deltoid may undergo adaptive shortening and the patient may regain power to lift the arm from the splint; when this much has been secured the arm should be slowly lowered, making sure always that the patient retains the power of elevation up to the right-angled position. Eventually he becomes able to raise the arm to this position when it is hanging free. He has then recovered use in the arm for light work at any level below the shoulder, and he may be considered as cured.

2. In cases in which the deltoid is lost or paralysed, and in which, therefore, there is no hope of recovery of voluntary power of abduction by means of this muscle, two courses are possible. In

those cases in which the shoulder joint is itself intact and freely mobile and in which the supraspinatus muscle is active, power of control of the shoulder can be re-established by using the clavicular part of the pectoralis major as an abductor; this muscle can replace the anterior part of the deltoid, and can thus give assistance to the supraspinatus which is sufficient to elevate the arm. In some cases the fixation of the arm in the fully abducted position for a period of months, with electrical treatment to the pectoralis major and supraspinatus, will suffice for this purpose. A more certain method is to transplant the pectoralis major outwards, thus giving it a more advantageous position for its new action. Figs. 84 and 85 show the amount of elevation of the shoulder that was obtained by

Fig. 85.—The result of the excision of the scar; transplantation of the clavicular part of the pectoralis major to replace the deltoid and covering the raw area with skin flaps. Good active abduction of the shoulder was present.

this method in a patient whose deltoid had been completely destroyed, its site being covered by a large adherent and ulcerated scar. The attachment of the pectoralis major to the clavicle was separated completely with a rugine, the clavicular part of the muscle was split completely away from the sternal part and the lower end separated from the tendon so that the entire clavicular portion of the pectoralis major was free and attached only by a pedicle which contained the nerve and the vascular supply; the muscle was then shifted outwards as far as this pedicle would allow, the upper margin was reattached to the periosteum of the outer part of the clavicle and acromion, the lower end of the muscle was fixed to the humerus at the level of the deltoid insertion, the shoulder being kept abducted to a right angle. The scar over the humerus had been previously

removed and the raw area was covered in by two flaps taken from the front and the back of the chest. The shoulder was kept in the fully abducted position for ten weeks, at the end of which time the patient was able to raise the arm off the splint; the shoulder was then gradually dropped, electrical treatment being given to the transplanted muscle.

3. When, in addition to destruction or paralysis of the deltoid, the head of the humerus has been destroyed, the best result will be obtained by securing complete bony fixation of the shoulder joint. It is not by any means easy to secure a complete ankylosis of this

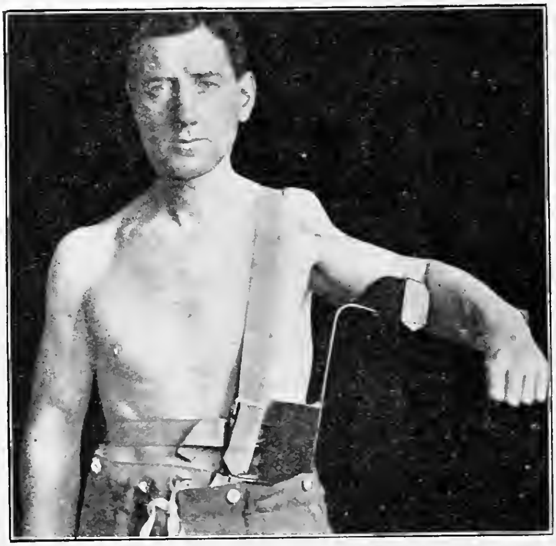

FIG. 86.—Absence of the upper 3 inches of the humerus, the result of primary excision. The deltoid muscle remained strong.

joint, but it is worth while to make the attempt if not more than two inches of the humerus have been lost. A free exposure is essential, and the ordinary incision along the anterior border of the deltoid is usually insufficient; as the deltoid muscle is no longer important a curved incision may be made from the coracoid process in front over the point of the acromion to the back of the shoulder and the joint exposed by cutting away the whole attachment of this muscle. The glenoid cavity should be gouged out until all cartilage is removed and cancellous bone exposed. The upper end of the humerus is then pointed so that it will fit into the cavity made in the glenoid with the arm abducted 60° and flexed slightly forward, then with a fine osteotome the acromion is divided near its origin from

the spine of the scapula and the superior ligament of the acromio-clavicular joint is also divided. The under surface of the acromion is chiselled away until cancellous bone is exposed. A hole is drilled through the acromion and another antero-posteriorly through the shaft of the humerus. The humerus is now driven into the glenoid fossa, the acromion bent downwards so as to lie in contact with it, and humerus and acromion sutured with strong kangaroo tendon. When the wound has been sutured the whole arm and chest are fixed in plaster and the position maintained for eight to ten weeks. If a secure bony ankylosis can be established the movements of the

Fig. 87.—The result of transplantation of 5 inches of the upper end of the fibula to replace the lost portion of the humerus.

scapula will allow the arm to fall to the side, to be elevated to the right angle, and to move forwards and backwards through a considerable range. The perfect stability secured completely restores the use of the hand for all work below the shoulder level.

4. In a certain number of cases the upper end of the humerus has been destroyed, several inches perhaps being missing, but the deltoid muscle is intact. When the loss of bone is too great to allow of adaptive shortening of the muscles an attempt may be made to secure return of function by grafting bone from another place. Figs. 86 to 89 show a patient in whom five inches of the upper end of the fibula, including the head of the bone, were transplanted into the humerus. The fibula was removed with its periosteum, one half

of its thickness was sawn away from the lower two inches, the medulla of the bone being opened. This portion of the fibula was fixed into a groove cut in the upper end of the shaft of the humerus and firmly sutured there with catgut, the head of the fibula was wedged between the glenoid fossa and the acromion, and the

Fig. 88.—Skiagraph of the case shown in Figs. 86 and 87 before operation.

shoulder fixed in an abducted position for ten weeks. The biceps tendon was removed from the fibula and reattached to the tibia: no disability whatever resulted in the leg. At the present time the arm is useful for light work and there is a small range of movement in the new false shoulder joint. The transplanted fibula appears in X-ray photographs to have its nutrition well preserved. Such an operation must be considered as still in the experimental stage:

only after a considerable time can we be sure that the transplanted bone is really preserving its full strength; there is always the possibility that its nutrition may ultimately fail and the bone crumble or become absorbed.

FIG. 89.—Skiagraph of the case shown in Figs. 86 and 87 after operation, showing the fibula *in situ*.

Stiffness and Ankylosis of the Shoulder Joint.

Cases of stiffness of the shoulder joint may be divided into three groups for clinical purposes. The first group includes those cases in which the bone surfaces are intact, the capsule undamaged and the muscles around the joint scarred to only a slight extent. The second group includes cases in which there has been an injury which has affected the shape of the articular surfaces, or an injury to the humerus in the region of the tuberosities, and cases in which the

capsule of the joint is considerably scarred, or in which there has been much injury to the surrounding muscles. The third group includes cases of bony ankylosis.

I. Slight Periarticular Adhesions.—In the first group the limitation of movement is due to slight adhesions usually around the joint, occasionally within it; such adhesions often give rise to much pain and disablement in spite of the fact that the movements of the joint are free through a very considerable range, in fact so free that unless tested in a particular way the limitation of movement may be overlooked. The test movement is that of external rotation in the abducted position. If the patient has been treated for an injury of the shoulder joint with the arm in a sling hanging by the side, abduction and external rotation are almost certain to become limited, and in the subsequent treatment by massage and mobilisation it may not be thought necessary to secure their restoration. It is, however, very essential, as the limitation of this movement is almost sure to produce pain whenever the arm is used for any work that is in the least heavy.

The treatment of these cases is simple, it consists in restoring the full range of movement. This may be possible by means of simple stretching movements and exercises, or it may necessitate an anæsthetic for breaking down the adhesions. For the latter purpose the patient should be given a full anæsthetic (chloroform or ether), an assistant fixes the scapula by downward pressure on top of the shoulder, and the surgeon then slowly and deliberately abducts and externally rotates the arm until it is elevated to its fullest extent. It is unnecessary in these simple cases to maintain the arm upon a splint after breaking down the adhesions.

It is not easy to force the movement of external rotation in the abducted position of the shoulder. The best method is as follows: The patient sits on a stool with his back to the masseur, raises both arms until they are abducted to a right angle and points the forearms upwards. The masseur puts one foot upon the stool and his knee against the middle of the patient's back; he then seizes each elbow from above with his corresponding hand, and by raising the elbow and forcing it backward he abducts and externally rotates the shoulders and can exert a very great force.

Active exercises, particularly hanging, heaving exercises, and exercises in the span-bending position are the best methods of securing the final complete mobility of the joint.

II. Injury to the Muscles, Capsule or Articular Surfaces.—In the second class of cases a full return of mobility in the shoulder is hardly to be expected; any attempt to secure it by mobilisation under

an anæsthetic will almost certainly be followed by a reactionary inflammation which will leave certainly no increase in mobility, and very possibly a diminution. Treatment in these cases should take the form of either gradual abduction upon an adjustable splint or abduction under an anæsthetic, with fixation in the abducted position; the arm should be kept abducted until the patient is able to lift it from the splint. It may then be gradually lowered while massage is given and exercises are carried out.

In some cases of injury to the articular surfaces movement of the joint remains persistently painful, probably because of the presence of irregularities of the joint surfaces and of intra-articular adhesions. This persistent pain may render the limb practically useless and be a more serious disability than that left when the joint is completely fixed. Such cases must be treated either by the application of a moulded leather splint covering the top of the shoulder and the adjacent parts of the front and the back of the chest, and enclosing the upper two-thirds of the humerus, and so fixing the joint, or else by operation designed either to produce a new freely mobile joint, or to produce a fixed ankylosis. The latter operation (arthrodesis) has already been described for cases of loss of the head of the humerus. In cases in which the head of the humerus is still present the operation is carried out in an exactly similar way, but is considerably easier because the greater size of the end of the bone enables good surfaces to be prepared for fixation to the glenoid cavity and to the acromion.

Arthroplasty of the Shoulder.—Arthroplasty of the shoulder must be considered to be still on its trial; it gives a mobile joint which may, however, be weak; in some cases the joint remains not only weak but also painful. If it is a failure, arthrodesis can be carried out at a later stage. In general a fixed shoulder joint is more suitable for a working man, so that arthroplasty should be reserved for men whose occupation does not involve much muscular effort and in whom mobility is specially desirable.

Two alternative incisions may be used; the ordinary one is a vertical incision along the interval between the deltoid and pectoralis major extended upwards in a curved direction over the top of the shoulder so that a flap of skin is reflected backwards and the surfaces of the deltoid and acromion exposed. The alternative incision (Kocher's) is an anteroposterior incision across the top of the scapula from the spine behind to the coracoid process in front, the flap of skin being turned outwards and the acromion and deltoid thus exposed. In either case a flap of subcutaneous tissue and deep fascia as large as possible is cut and turned downwards, being left

attached by a pedicle situated over the interval between the deltoid and pectoralis major about two inches down the arm. When the vertical incision is used the rest of the operation is carried out as in the classical excision of the shoulder, the glenoid cavity is cleared and excavated into a slightly concave form, comparatively little of the head of the humerus need be removed, and the tuberosities must not be interfered with. The stump of the humerus is rendered convex. The exposed surfaces of bone should be smoothed down with a file or burr. The flap of fascia is next inserted between the deltoid and pectoralis major and sutured over the stump of the humerus, the muscles and skin are sutured with drainage and the arm fixed in the position of right-angled abduction. When Kocher's incision has been used the joint is exposed by dividing the acromion process and acromio-clavicular joint, the acromion and deltoid muscle being turned outwards. The rest of the operation is carried out as before, the acromion being finally sutured back into place with kangaroo tendon.

The arm should be kept in the abducted position until the patient is able to elevate it from the splint, electrical treatment being given to the deltoid as soon as the wound is healed.

When the glenoid cavity or upper end of the humerus have been badly splintered, this operation is not likely to be successful and arthrodesis is to be preferred.

III. Bony Ankylosis.—Bony ankylosis of the shoulder, provided that the position is good, gives a very good functional result. The best position is that of abduction of 60° with slight forward flexion. If the scapula movements are good the arm which is ankylosed in this position is useful for almost any variety of work, provided that elevation beyond the right angle is not required.

When a shoulder is ankylosed in a bad position, for example close to the side, or rotated inwards, or outwards, it should be treated by a simple osteotomy carried out just below the tuberosities, the position being corrected at the time of operation and the whole limb and chest being fixed in plaster of Paris in the corrected position. As a rule this osteotomy can be carried out through healthy bone, avoiding the site of the injury.

Chronic Osteomyelitis of the Humerus.

The sequestra which form in a septic compound fracture of the humerus do not tend to become enclosed by new bone to the same extent as do those in the femur and tibia. This is due to the fact that they are less massive and that they separate more rapidly so

that they can often be extracted before they are completely enclosed. In the humerus it is always worth while to make a simple exploration of a persistent sinus, removing all sequestra that can be felt and disturbing the surrounding parts only sufficiently to enable the sequestra to be extracted.

In some cases, however, it is necessary to explore the bone widely, to remove the sequestra, and to lay open a cavity and fill it with muscle as described in Chapter I. The route by which the bone must be explored is settled partly by the site of the sinus and of the bone cavity, partly by the arrangement of the important nerves of the arm. Sinuses leading to a cavity in the head of the humerus can be best explored by an incision along the anterior border of the deltoid, or through the anterior part of this muscle. In the shaft of the bone, as far as the junction of the middle and lower thirds, the line of the external intermuscular septum gives the best approach to the bone. In exploring in this region the musculo-spiral nerve must always be remembered. It can best be avoided by keeping very close to the bone and working subperiosteally if possible. The lower third of the bone is very difficult to approach; perhaps the best method is to work along the interval between the brachialis anticus and supinator longus, identifying the musculo-spiral nerve and lifting it outwards with the latter muscle.

Mal-united Fractures of the Humerus.

Mal-union of the humerus sufficient to cause a functional disability is rare. It is very seldom that angulation in either the antero-posterior or lateral direction is sufficient to affect use, its importance is usually purely æsthetic. When it is thought necessary to correct alignment of the bone, this should be done, if possible, by a simple osteotomy carried out a short distance below the original fracture.

Ununited Fractures of the Humerus.

Non-union of the humerus is frequent and constitutes a difficult surgical problem. Efficient splinting of the arm in the case of septic compound fractures is notoriously difficult, and the dependent position of the limb tends to distract the fragments of bone from each other and thus to increase the probability of failure of union. In addition there appears to be a prevalent belief that in fracture of the humerus extension upon the lower fragment is necessary; this is undoubtedly a fallacy; many fractures of the humerus should be treated rather by forcing the fragments together than by applying an extension which tends to separate them.

When union in the humerus is delayed, that is when the fragments

are united by soft callus which allows of slight mobility and which is slow in ossifying, all that is required is the fixation of the arm in a suitable splint and the application of treatment by passive congestion. The splint should consist of a moulded leather support enclosing the whole arm, reaching down posteriorly to the olecranon, anteriorly to the fold of the elbow with the joint flexed to a right angle. This leather case is attached below by steel joints to a similar case which encloses the forearm, the steels being curved in above the elbow so as to secure a hold upon the supracondylar ridges. The upper end of the arm-case should reach on the inner side as far as the axillary folds, on the outer side it should cover the entire deltoid and reach as far as the acromion. Two straps attached to it should pass across the front and back of the chest and form a loop under the opposite axilla. In this support the arm can be used for light work.

In complete non-union of the humerus, treatment by a very drastic operation is necessary, simple methods of freshening the ends of the bone and fixation by sutures, wires, or plates are very likely to be unsuccessful, and they involve as much risk as does a more complete operation. Two alternative methods may be used.

1. The upper and lower fragments can be exposed and one half of each cut away for a distance of $1\frac{1}{2}$ inches; this will usually suffice to make sure that healthy bone is exposed in each fragment. The fragments are then overlapped to this extent, drilled in two places and sutured.

2. If there has already been considerable loss of bone, the further shortening required by this operation may be undesirable. The fragments may be exposed, their scarred extremities cut off, and their ends placed in contact and joined either by a strong lateral graft from the tibia, or by an inlay graft taken from the same bone. No attempt should be made to bridge the gap in the humerus by means of a graft; the fragments of the bone should always be brought into contact with each other. Whichever method is adopted the whole arm and chest should be fixed in plaster of Paris at the time of the operation, the arm being abducted to a right angle and the elbow flexed. Fixation sufficient to relieve any tension upon the point of suture is difficult, and it is for this reason that abduction is advisable, for if the arm is kept at a right angle the lower fragment and the forearm no longer tend by their weight to throw a strain upon the point of suture. Fixation in this position should be maintained for about eight weeks. If a window is cut in the plaster at the time of operation the skin sutures can be removed without disturbing the fixation.

Flail Elbow Joint.

A flail condition of the elbow joint is common. Wide excisions of this joint are often carried out in order to secure adequate drainage, possibly also the surgeons who perform them have the idea that these wide excisions are advantageous because they will ultimately leave a mobile joint. If excisions are performed with this end in view, they should be condemned, for the very weak mobile joint left by a primary excision gives a very much poorer functional result than does an ankylosed elbow. Probably the dependent position of the arm by distracting the bones of the arm and forearm is an accessory in the production of the flail condition of the elbow seen after these excisions. A further complication is the fact that the attachments of the triceps are very commonly lost, so that in the flail elbow active extension is impossible; nerve injuries, more particularly of the ulnar nerve, are frequent complications.

The treatment of these flail elbows is exceedingly difficult, and can at present only be considered to be in the experimental stage. The possible methods are the following :—

(i) In certain cases fixation of the elbow in a flexed position in plaster of Paris for a period of one to two months, with electrical treatment of the biceps, will lead to a recovery of power in the latter muscle with adaptive shortening which restores a certain amount of stability in the joint and the power of active flexion, when the plaster case is removed. This method, followed by re-educational exercises, is worth a trial in all cases in which the removal of bone has not been very wide.

(ii) In more severe cases the best result will be obtained if ankylosis of the elbow can be secured; this, however, is a surgical procedure of very great difficulty, and at the present time failure may be said to be more probable than success. Two methods may be tried :—

(*a*) The ends of the humerus and ulna may be exposed from behind, cut to fit each other, and fixed together by a graft of bone. The best angle for fixation is about 110°. A curved graft with its upper and lower parts lying at this angle to each other can be obtained from the posterior part of the crest of the ilium. This method is worth attempting in cases in which the superior radio-ulnar joint is intact.

(*b*) When the superior radius ulnar joint is destroyed, or the bones ankylosed together, a peg of bone cut from

the tibia may be driven through a hole bored in these bones and upward for two inches or so into the medulla of the humerus. The elbow should be fixed at between 90° and 110° with the forearm in a mid position between pronation and supination.

iii. When the forearm bones are intact and the loss is of the condyler part of the humerus, it may be worth while to attempt the fixation of two lateral grafts to the inner and outer side of the humerus in such a way that they enclose the upper end of the ulna. It may be possible in this way to secure a stable mobile joint.

iv. In many cases the permanent use of a supporting appliance is the best method. A cage consisting of moulded leather pieces enclosing the arm and forearm with lateral steels jointed at the elbow can be used. The chief difficulty in its application is due to the loss of the condyles of the humerus, for when these are lost there is nothing to keep the steel elbow joint correctly centred. As a rule, when the condyles of the humerus are lost, the best functional result will be obtained by enclosing the arm, elbow and forearm in a leather splint, fixing the joint completely at whatever angle is desired.

Stiffness and Ankylosis of the Elbow Joint.

Cases of restriction of mobility of the elbow joint may be classified clinically into the following groups :—

I. Restriction of movement by periarticular adhesions and by muscular rigidity without damage to the articular surfaces of the bones.

II. Ossification of the muscles round the joint due to the condition of traumatic myositis ossificans, sometimes called ankylosis by encircling bone.

III. Alteration of the articular surfaces due to a fracture which involves the joint, movement being free through a limited range.

IV. Similar cases with intra-articular changes, but with a small range of mobility which is painful.

V. Cases of bony ankylosis or of close fibrous ankylosis with very little movement.

It is very rarely that stiffness of the elbow joint can be treated by simple mobilisation of the joint under an anæsthetic followed

by massage and active exercises; even in cases in which stiffness is definitely due to periarticular adhesions the forcing of movement either with or without an anæsthetic is very apt to start an inflammation which results either in fibrosis or in ossification in the muscles, and which in this way further diminishes the mobility. The occurrence of myositis ossificans around the elbow has already been alluded to and its treatment described. The liability of this joint to become surrounded with new bone is so great as to render it undesirable, as a rule, to attempt to force movement. We should substitute a gradual change of position of the joint brought about by the use of a splint or a sling and the improvement of mobility which active use induces, for any attempts to force the movement passively. In the first group of cases, those with periarticular adhesions, we may put the elbow once through its full range of movements by the use of a splint and a sling. Suppose that the original range of movement is from 90° to 140°, by fixing the arm and forearm in plaster of Paris with a rack splint at the elbow the joint can be racked out until it is fully extended. It will then probably be found that the range of movement is from 130° to 180°; the position of the elbow has been altered, but the range of movement has not been increased. By the use of a collar and cuff sling, the joint may now be forced into a position of flexion, perhaps as far as 50°. It will then be found that the range of movement is from 50° to 100°; again the range of movement has not been increased. We now know, however, that mobility through the range 180° to 50° is possible, and in all probability will ultimately become free. Attempts to hurry the return of active movement through this range by giving forced movements and massage are almost certain to be unsuccessful. The best method of securing this return is to put the patient on to active work in the workshops and in the gymnasium; his movement will then return automatically.

In those cases in which the articular surfaces of the bone have been damaged we may take it that a limited range of useful painless mobility will usually result. It is of very little use attempting to increase this range of movement by any mechanical means. We should see that the angle through which the elbow moves is the most useful one for him in his ordinary life and in his trade; this usually means that the mean point of the range of movement should be about 110°. If his total movement amounts to 60°, this should be from flexion to 80° to extension to 140°. If the elbow has become fixed so that the optimum angle (110°) is not included in its range of movement, an attempt should be made to alter this by the use of the rack splint or of the collar and cuff sling. If this is not

possible, we must consider the joint to be one which is fixed in a bad position and which requires operative treatment.

The next group of cases consists of those in which there is a limited range of movement which is painful. Very often this condition is due to progressive inflammatory changes either in or around the joint; it is therefore best treated by complete rest to the joint by fixation in plaster of Paris. It is not uncommon to find that immobilisation of the elbow for a period of one or two months will restore a considerable range of mobility, or render the movement that was present painless. When movements continue to be painful in spite of complete rest, the joint must be treated either by operation or by fixation in a splint for a longer period.

Bony ankylosis and fibrous ankylosis of the elbow with little or no mobility give a good functional result provided that the position is a good one. No treatment is necessary in these cases except for bad position or because a mobile elbow is essential for a patient's particular occupation.

Arthroplasty of the Elbow.

The elbow joint gives particularly good results after the operation of an arthroplasty, and as mobility in this joint is often desired, the operation is one which may be safely recommended in properly selected cases. The cases that are suitable are the following:—

A. Bony ankylosis in a bad position—that is, extended more than 120° or flexed to less than the right angle; in other cases of bony ankylosis the operation should only be recommended when the occupation of the man necessitates a mobile elbow, or when both elbows are ankylosed. For a working man bony ankylosis of the elbow in a good position is in many cases better than the result given by an arthroplasty.

B. Cases with a small range of movement which is painful, or in which the range of movement is in a bad position.

C. Cases in which, although there is a moderate range of useful movement, forcing this movement in the direction either of flexion or of extension causes pain.

In selecting cases the amount of damage to the joint and surrounding part must be considered; any considerable amount of scarring over the back of the elbow and forearm will make the operation much more difficult, and much deformity of the shape of the ends of the bones will also make the operation more difficult and necessitate variations from the usual operation here described.

In certain cases the superior radio-ulnar joint is intact, and movements of pronation and supination free. It is then unnecessary to interfere with this joint, or to touch the head of the radius during the operation. The following description applies to these cases: A tourniquet should not be used. A longitudinal incision about eight inches long is made down the back of the arm and forearm with its centre over the tip of the olecranon, the skin is reflected inwards and outwards, most of the subcutaneous fat being left attached to the deep fascia. The next step is the preparation of a flap of fascia for subsequent insertion in the new joint; this flap should be taken, if possible, from the back of the forearm, and should be about four inches in its vertical measurement, and as wide as possible. It

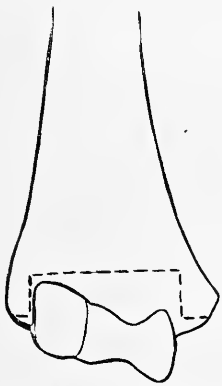

Fig. 90.—Method of shaping the lower end of the humerus in arthroplasty of the elbow. The dotted line represents the line of the section.

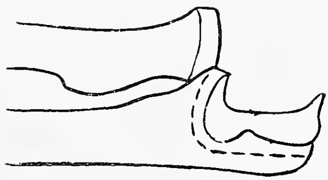

Fig. 91.—Method of shaping the ulna in arthroplasty of the elbow. The dotted line represents the line of section.

includes the whole of the deep fascia and aponeurosis covering the muscles, the muscle fibres being left bare. It is turned upwards and inwards, being left attached by a pedicle about an inch wide situated over the back of the internal condyle of the humerus. In separating the flap over the interval between the olecranon and the internal condyle great care must be taken to avoid injury to the ulnar nerve.

The inner and outer borders of the tendon of the triceps are next defined and a blunt elevator passed beneath the tendon, which is then split into a superficial and a deep part for a distance of one inch above the olecranon. The superficial half of the tendon is divided above, the deep half is separated from the olecranon. Working with a periosteal elevator and with a knife, the lower end of the humerus and the upper end of the ulna are next cleared on the inner side, keeping very close to the bones and lifting the ulnar nerve and the

muscles in one mass. In a similar way the muscles arising from the external condyle should be stripped back, and this and the orbicular ligament of the radius cleared.

If the ankylosis is fibrous the joint can now be forced open by full flexion. If the ankylosis is bony, a curved osteotome should be inserted on the inner side between the ulna and the humerus and driven transversely so as to separate the bones; this enables the joint to be forced open. The ends of the humerus and the ulna are next shaped with an osteotome in the way shown in the diagram. The

Fig. 92.—Movement photograph showing the range of active movement in the elbow after an arthroplasty. The elbow was ankylosed by bone in the fully extended position as the result of the treatment of a compound fracture of the lower end of the humerus by prolonged fixation upon a straight Thomas's splint.

olecranon fossa of the humerus should be cleared out thoroughly, the lower edge of the bone cut into a transversely cylindrical form, and the front of the bone carefully cleared and pared down. The ulna should be cut away freely, only about half the thickness of the olecranon being left, and only a small part of the root of the coronoid process. If there is any ossification in the brachialis anticus muscle this must be removed. The surfaces of the humerus and of the ulna should be smoothed down with a file or burr. The flap of fascia is next sutured over the whole of the cut surface of the humerus, care

being taken to carry the flap well up in front of the bone. Fine catgut sutures are best for this purpose. The two halves of the triceps tendon are then sutured in their original position and the skin incision closed, a drain being inserted for forty-eight hours. The arm is fixed on a splint at a right angle until the wound is healed. The patient is then encouraged to carry out active movements, and mobility is restored by active use, only very gentle massage being employed, and any attempt to force movement being avoided.

When the superior radio-ulnar joint is fixed, it will probably be best to do the operation in two stages: first to excise the head of the radius and to restore pronation and supination, then at a later stage to carry out arthroplasty of the elbow joint proper. If the whole operation is carried out at once the subsequent attempts to restore pronation and supination are very likely to twist the ulna on the humerus and thus to render the elbow joint less stable than it should be.

Chronic Osteomyelitis of the Radius and Ulna.

In chronic osteomyelitis of the forearm bones the sequestra are usually small and do not tend to become deeply enclosed in new bone, consequently the simple removal of these sequestra from the sinus is sufficient in most cases. When, however, there is a portion of one of the bones missing, and it will be necessary to replace this with a bone graft, a more thorough preliminary operation is advisable; such an operation should take the form of an excision of the superficial scar and of sufficient of the deep scar tissue to make certain that there is no remaining sequestrum, or septic pocket. The route by which the bones are explored will usually be settled by the site of the scar, or scars, but whenever possible the ulna should be explored by an incision along its posterior border between the flexor carpi ulnaris and the extensor carpi ulnaris, and the radius along its outer border between the supinator longus and the extensor carpi radialis longior. Exploration of the ulna along its whole length is simple, but the upper and lower ends of the radius are difficult of access. At the upper end the supinator brevis must not be divided but must be stripped up from its lower border; if the muscle is incised there is a serious risk of damaging the posterior interosseous nerve. At the lower end the extensor muscles of the thumb must be lifted from the posterior aspect of the bone without being damaged.

Synostosis of the Radius and Ulna.

In fractures of the forearm bones, particularly in the comminuted fractures due to gunshot wounds, bony union between the radius and

ulna is common. The result, a complete abolition of the movements of pronation and supination, may be very serious. Operative treatment of this condition is not very satisfactory, as there is a great tendency for the bony bridge to reform. In spite of this it is usually desirable to make the attempt to separate the bones by a thorough operation. If the union is above the tuberosity of the radius, it will usually be necessary to excise the head of this bone, dividing the neck of the bone below the level of the synostosis and removing the whole of the part above this. This operation is carried out through an incision over the posterior aspect of the head of the radius, care being taken to strip the supinator brevis downwards and not to divide the muscle. In synostosis at a lower level it is better to make the incision along the posterior border of the ulna, reaching the interosseous membrane by lifting the extensor carpi ulnaris from the bone; in this way the muscles of the extensor aspect of the forearm are raised from the ulna and interosseous membrane in one mass, and their nerve supply from the posterior interosseous nerve is safeguarded. The bridge of bone must be cut away very thoroughly, and the surfaces of the radius and ulna, to which it is attached, should be smoothed, or even excavated. As soon as the wound has healed the elbow and forearm should be enclosed in supinating plaster and the forearm held alternately in full supination and full pronation for periods of a week at a time. If it is apparent that the bridge of bone is reforming the forearm should be fixed in that degree of pronation which would be most useful to the patient, usually semi-pronation.

Mal-union of the Radius and Ulna.

Mal-union of the radius and ulna sufficient to affect the functional utility of the arm is not uncommon, most often it takes the form of an angulation of the ulna or of both bones towards the ulnar side. When this condition is present it will often be found that the union is incomplete, so that under an anæsthetic the bones can be straightened and the limb fixed in plaster in the corrected position: if union is more secure, a reconstruction of the fracture by an open operation is advisable, the bones being again brought into good position and fixed.

A second form of mal-union is that in which the upper end of the radius is supinated and the lower end pronated; this is an important deformity, because it prevents full supination of the forearm. It can be corrected with comparative ease by an osteotomy of the radius, which is best carried out a little above the attachment of the pronator radii teres. The forearm should be fully supinated

and fixed in plaster of Paris in this position with the elbow flexed to a right angle.

Non-union of the Radius.

Non-union is more common in the radius than in any other bone; it may occur in any part of the shaft, but is especially frequent in the lower half, where the bone is often extensively comminuted, without any fracture in the ulna or with only a simple fracture of that bone. The result of an ununited fracture of the radius is to produce an almost completely useless hand. The lower fragment of the bone tilts towards the ulna and the hand is deviated towards the radial side, the styloid process lying at a higher level than that of the ulna. There are often associated injuries of the tendons and muscles, particularly of the extensor muscles of the thumb. An injury to the median nerve is not an uncommon complication. Large adherent scars are also frequent, and are important because these may interfere with the success of an operation unless they can be completely removed.

Before undertaking an operation for grafting the bone a preliminary exploration to make certain that there are no remaining sequestra is very often advisable. At this preliminary operation the old scars should be excised. The method of grafting the radius has already been sufficiently described in the chapter on non-union of bones. The best line for exposing the bone is along the posterior edge of the supinator longus; a good view of the posterior and external surfaces of the bone can here be obtained. To secure a proper alignment it is necessary to remove all the scar tissue which lies between the fragments, to lever the lower fragment away from the ulna and to rotate it into the supinated position. An attempt should be made to restore the full length of the bone, but it will not matter if at the finish the styloid process of the radius is left still a little above the level of that of the ulna; a slight radial deviation of the hand will remain, but this is not of importance. Any reconstruction of the tendons, or transplantation, should be left for a subsequent operation.

Non-union of the Ulna.

Non-union of the ulna is also common, but is much less important. When it occurs low down in the shaft it affects the utility of the hand comparatively little. In every case before a bone graft is undertaken, a careful investigation should be made to determine whether the disability present is really due to non-union of the bone. In

many cases it will be found that associated injuries are really responsible for the disablement, so that the restoration of the bone by a graft, although it is a very satisfactory surgical procedure, is hardly justified. In the upper half of the bone non-union is important, and an operation for grafting should practically always be carried out.

A preliminary operation is advisable as in the case of the radius. The bone should be approached along its postero-internal border

Fig. 93.—Flail wrist joint due to loss of the lower end of the radius.

Fig. 94.—The result of transplantation of a portion of the lower end of the ulna to the radius in the case shown in Fig. 93.

between the flexor carpi ulnaris and the extensor carpi ulnaris. There is usually no considerable displacement of the fragments to be corrected.

Non-union of the Radius and Ulna.

It is rare to find both bones of the forearm ununited. When this condition is present there are usually associated injuries of the muscles

or tendons and nerves so that a very difficult problem in reconstructive surgery is presented. An operation for grafting both bones simultaneously may be carried out, but this is a very lengthy and formidable procedure. A simpler method is to explore the bones, to cut each fragment away on one side and to overlap the fragments and suture them, thus very considerable shortening of the forearm; this shortening may be amply justified by the necessity for repairing and suturing the tendons and nerves. Even in an apparently hopeless case an operation for the repair of bones, tendons and nerves in the

Fig. 95.—Skiagraph of the case shown in Fig. 93 before operation.

forearm is worth undertaking. If a grip in the fingers can be restored thus, however feeble, it may be in the end more useful than an artificial hand.

Flail Wrist Joint.

A flail condition of the wrist joint most often results from a loss of the lower end of the radius; it will almost always be associated with injuries to the tendons. It is, however, worth while to attempt its repair, an ankylosed wrist being our object. When the lower end of both ulna and radius are destroyed, the best method will be to

point the lower end of these bones and to drive them into the carpus with the wrist extended forty-five degrees. When the radius only is destroyed a portion of the lower end of the ulna may be removed and transplanted into the radius, the cut extremity of the ulna and the distal extremity of the graft being driven into the carpus. Any necessary repair or transplantation of the tendons should be left until a second operation.

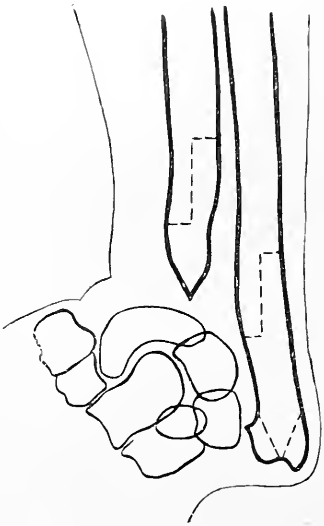

Fig. 96.

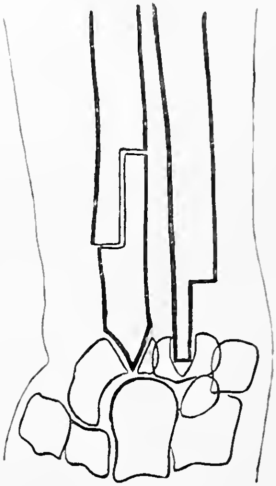

Fig. 97.

Diagram of the method of operating upon the case shown in Figs. 93 to 95. The bones were cut along the dotted lines shown in Fig. 96; the separated portion of the ulna was then fixed to the radius as shown in Fig. 97, and both bones driven into the carpus.

Injuries of the Carpal and Metacarpal Bones.

Fracture of the carpal bones is not uncommon. In the presence of sepsis it usually leads to ankylosis of some of the bones to each other, and perhaps of the wrist joint also. If the tendons have escaped, the disability left from actual ankylosis between the carpal bones is less than might be expected, provided that the trapezium and its joint with the first metacarpal, and the joints between the bases of the second to fifth metacarpals are not involved. In simple injuries a fracture of the scaphoid is frequent. If it is recognised early and the wrist immobilised in the extended position, a good functional result may be expected, although bony union of the fracture does not take place. When the fracture has escaped early recognition the two fragments commonly remain mobile upon each other,

and in certain positions the wrist may give way suddenly with a slight stab of pain. In these cases there is usually a limitation of full extension and of radial abduction at the wrist, with a little tenderness on pressure over the region of the scaphoid. Treatment by excision of the smaller fragment of the bone will usually give a good result.

Dislocation of the semilunar forwards is another not uncommon injury. The bone lies in front of the rest of the carpus, with its concave surface facing forwards. In this position it forms a slight prominence in front of the wrist and by pressing upon the flexor tendons greatly interferes with the use of the hand. The condition should be treated by excision of the dislocated bone. Both the

Fig. 98.—Gunshot wound of the hand with mal-union of the metacarpal bones of the middle and ring fingers. The tendons of the middle finger were also injured, and this finger was amputated, as it interfered with the use of the hand.

scaphoid and the semilunar may be dislocated forwards, or fracture of the scaphoid may be combined with the dislocation of the semilunar. In these conditions, if necessary, both bones may be excised.

Mal-union of the metacarpal bones is extremely common; the fragments are usually united with an angle backwards, so that the head of the metacarpal is less prominent than it should be, and extension of the finger is apparently incomplete. If these fractures are uncomplicated by damage to the tendons and interossei, they may be treated by an osteotomy and a correction of the deformity. Very often, however, the damage to the surrounding tendons and interosseous muscles, and the consequent interference with the mobility of the finger, is such as to make it very doubtful whether a useful finger can be obtained. In these cases an amputation of the finger

may be advisable in order to remove a digit which is interfering with the use of the rest of the hand.

Non-union of the metacarpal bones is also frequent; it is nearly always complicated by injuries to the tendons and to the interossei, and for this reason operations for bone-grafting have so far not been extensively tried. If there is a reasonable prospect of restoring the function of the tendons and muscles, it is worth while to graft the bone, if not an amputation through the site of the fracture is advisable. When several fingers are affected it is, of course, far more important to try reparative operations instead of carrying out an amputation.

Mal-union of the phalanges in gunshot fractures is usually com-

FIG. 99.—Non-union of the metacarpal bone of the little finger with injury to the extensor tendon and of the interossei of the 4th space. The little finger was amputated and its short muscles reattached to the ring finger.

plicated by injury to the tendons or joints. It is a comparatively simple thing to correct a faulty union by an osteotomy, but it will usually be found that the disability is due rather to the associated conditions than to the mal-union of the fracture.

Stiffness and Ankylosis of the Joints of the Hand.

Normal Shape and Movements in the Hand.—In the position of most complete rest, the hand is held with the wrist extended about 40°, the metacarpo-phalangeal joints and the interphalangeal joints each flexed about 30°, the thumb being slightly abducted and opposed and the whole hand assuming the attitude which would be adopted in grasping a spherical or nearly spherical object with a diameter of about two and a half inches. In this position the front

of the wrist is concave transversely, the palm is hollow, and there is a further transverse concavity across the heads of the metacarpal bones. All the muscles, extrinsic as well as intrinsic, are in a condition of slight relaxation; that is to say, no muscle is stretched and none is fully contracted. This position is undoubtedly the ideal one for splinting when complete rest to the joints and muscles is desired. If ankylosis of any of the joints occurs, the best functional result will be obtained if the joint has been held in the position thus assumed. If the joints become stiff, from periarticular changes, their stiffness will not be in an extreme position and will be much more easily overcome. For example, if the metacarpo-phalangeal joints are allowed to become stiff in the fully-extended or hyperextended position, it is a matter of extreme difficulty to overcome the fixation and to start movement in the direction of flexion. If, however, the fingers are flexed 30° to start with it is comparatively easy to secure further flexion.

The transverse concavity of the palm of the hand varies with every movement. In the proximal part of the hand this concavity lies between the bases of the thenar and hypothenar eminences; it is increased when the thumb and little finger are opposed, and diminished when the digits are widely separated. It never disappears. In the distal part of the hand the concavity is formed by the heads of the metacarpal bones. These do not articulate with each other, but are connected by ligaments which allow of a considerable amount of play; the extent of this movement depends partly upon the restriction by these ligaments, partly upon the movement allowed at the articulations between the bases of the metacarpal bones. These movements between the bases of the metacarpal bones of the fingers are small in degree, but very important. By means of them the palm is adapted to the exact shape required to grip objects of various shapes and sizes. If they are lost, as in a paralysis of the ulnar nerve, the grip remains adequate for a cylindrical object, but adapts itself badly to anything spherical. Apart from this interference with the grip, the loss of the intermetacarpal movements affects the accuracy of the finer movements of the individual digits; for example, opposition of the thumb in turn to the middle, ring and little finger is inevitably accompanied by an increasing hollowing of the palm. When the hand is fully spread the transverse concavity opposite the heads of the metacarpal bones almost disappears; it can be completely abolished or converted into a convexity by a little passive force. When the thumb and little finger are closely opposed, the concavity becomes very considerable, the whole hand being narrowed to the extent

of as much as an inch (measured across the heads of the second to fifth metacarpal bones). Fixation of the hand upon a splint which keeps the palm flat and the metacarpo-phalangeal joints fully extended is a common cause of loss of these intermetacarpal movements.

In the thumb the movement at the carpo-metacarpal joint is the most important. Here the movements are in two directions: (1) adduction towards the second metacarpal bone and abduction away from it, and (2) flexion or opposition in which the first metacarpal bone comes forward in front of the palm and is approximated to the fifth metacarpal, the reverse movement being extension. Pure adduction or abduction of the thumb does not affect the concavity of the palm. Flexion or opposition increases it, extension diminishes it. The best position for fixation of the thumb in splinting is in abduction with opposition half-way towards the little finger, so that the first metacarpal lies in a plane which is almost at right angles to that of the other metacarpal bones. This, with slight flexion at the metacarpo-phalangeal and interphalangeal joints, coincides with the resting position of the hand already described.

Extra-articular Stiffness.—Stiffness of the hand due to conditions which do not involve the actual joints is a common result of injuries not only of the hand itself, but also of any part of the limb above. In many cases the lack of movement is a purely functional condition, in others there exist spasm or contracture of muscles, shortening or adhesion of tendons or peri-articular fibrosis. It is important to determine as accurately as possible the exact pathological cause of the stiffness in any individual case, as upon this the line of treatment must depend. These causes may be briefly classified as follows:—

1. Functional conditions due to disuse and lack of proper re-education after an injury.

2. Muscular spasm, due to irritation of a nerve, or to a painful scar, or of a purely functional nature.

3. Contracture of muscles by fibrosis as the result of a direct injury (scarring in the muscle), or as the result of an ischæmic condition.

4. Contracture of muscles the opponents of which have been paralysed or over-stretched.

5. Adhesion of muscles or tendons to a scar.

6. Localised adhesion of one or more tendons in a deep scar.

7. Periarticular fibrosis around the joints themselves, which may be the result of local sepsis (cellulitis), or which may follow sepsis at a distance.

This last condition requires some further mention. It is possible to maintain the hand in the resting position which has already been

described for a long period without much stiffness resulting. Yet it is a common observation that in military surgery the retention of a hand upon a splint for weeks or months during the period necessary to secure union, for example, of a fracture of the humerus, results often in a most intractable stiffness. The causes of this are probably twofold. In the first place, in many of these cases there is throughout the whole time a greater or less amount of chronic œdema of the hand. Probably in septic compound fractures this œdema is not aseptic, although suppuration does not occur. There is a mild infection of the cellular tissues of the hand, resulting in a certain amount of organisation of the effusion and a consequent fibrosis around the joints and tendons. But this form of stiffness is not confined to cases of septic compound fractures; it may occur in aseptic cases and in cases which have never been œdematous. In these the position of splinting must be blamed. If the hand has been held with the fingers fully extended, the constant strain upon the anterior ligaments tends to produce alterations in the capsule of the joints and resulting stiffness. Or if the hand has been allowed to remain with the fingers tightly closed a stiffness in this position may result. There is no doubt that whenever possible in injuries of the upper limb small active movements of the fingers should be encouraged from the earliest possible moment. Active movements are for this purpose of far greater value than are passive movements or massage, and, of course, such movements must be restricted if they will interfere with the proper retentive splinting of a fracture.

The causes of stiffness enumerated above must not be looked upon as isolated conditions; they may be, in fact are, generally combined, so that a functional disuse is added to a pathological rigidity, spasm of certain muscles coincides with shortening of others, or adhesion of tendons accompanies fibrosis around the joints.

The treatment of these conditions is extremely difficult. It must, of course, vary according to the actual lesions present, but certain general principles may be laid down. In the first place, it is advisable to get the wrist into a position of extension as early as possible. Active use of the fingers is difficult or impossible as long as the wrist remains contracted in a position of flexion. Then, without delay, an endeavour should be made to get over the stiffness in an extreme position of flexion or of extension of the fingers, moulding the hand into the ideal resting position already described. In severe cases this will have to be done by methods of continuous splinting or by a continuous pull. In less severe cases daily manipulations will suffice. Forced movement under anæsthesia may be necessary; if so, this, as a rule, should be followed up by splinting by methods

which allow of daily manipulations. The method of forcibly flexing fingers that are hyperextended and fixing them in plaster of Paris in the flexed position has been extensively tried and is found to lead in many cases to a fresh stiffness in the flexed position. Forced movements under anæsthesia should not be carried too far; if too much is attempted a reactionary inflammation will very probably add to the rigidity. Finally, it must be remembered that our ultimate

Fig. 100.

Fig. 101.

Contracture of the flexor tendons; with the wrist extended the fingers were flexed; the fingers could be extended if the wrist was allowed to flex.

aim is to secure useful active movement. As soon as possible the patient must be made to help himself by active use of the hand; for a very little active use is far more valuable in treatment than a great deal of passive manipulation.

In purely functional conditions, without spasm or contracture, exercise in the gymnasium, games and work are the best lines of treatment. When spasm, due to nerve irritation, is present a similar

course may be pursued with whirlpool baths in addition, but progress must be expected to be slow.

When the flexor tendons are contracted as the result of scarring, or of an old ischæmic condition, they can usually be stretched by one or other of the following methods:—

1. In those conditions in which if the wrist is flexed the fingers can be extended, but if the wrist is extended the fingers become

Fig. 102.—The hand splinted by applying small splints to each finger and then a long cock-up splint to the whole hand.

flexed (see Figs. 100 to 103). With the wrist fully flexed, small finger splints are strapped on to each finger separately, reaching from the head of the metacarpal bones to the tip of the finger. The forearm and hand is then bandaged firmly on to a long cock-up splint; continuous pressure is thus brought to bear upon the shortened muscles.

Fig. 103.—Method of applying the small finger splints. (This photograph was taken after most of the contracture had been overcome.)

2. The wrist and forearm may be fixed in plaster of Paris with the splint shown in Figs. 104 and 105 incorporated. Tapes are then attached by strapping to the extremity of each finger; by tying these tapes to the cross piece at the end of the splint a continuous pull is brought to bear upon the shortened muscles. The tapes can be untied daily and the fingers moved.

When one or more tendons is adherent in the front of the wrist

or palm these attempts to stretch out the fingers may fail: the finger returns to the flexed position immediately the extension is relaxed; in such cases the tendon should be explored and freed. It is then necessary to hold the finger in a fully extended position for a fortnight to prevent adhesions reforming in the same place.

When the stiffness is due to changes around the joints and the fingers are in the flexed position, the method shown in Figs. 104

Fig. 104.

Fig. 105.
Verrall's finger-extending splint applied.

and 105 may be used. When the fingers are hyperextended at the metacarpo-phalangeal joints, it is a very difficult matter to start the movement of flexion. A good method is to use the splint shown in Figs. 106 and 107. This consists of a short cock-up splint with a projection from the front of the wrist which ends in a cross bar placed exactly opposite the metacarpo-phalangeal joints, a second cross bar is placed close down in front of the wrist, the splint is fixed to the forearm and wrist in plaster of Paris. It must not extend beyond the transverse fold in the palm

which marks the line of movement at the metacarpo-phalangeal joints; tape extensions are attached to each finger, and these are tied down in the first place to the further cross bar. By this means a pull is obtained which directly flexes the metacarpo-phalangeal joints; the counter pressure is against the front of the wrist, it therefore does not tend to pull the splint off, or to push it further up the arm. When the metacarpo-phalangeal joints have been flexed to a right angle, the tapes may be tied to the proximal cross bar to flex the interphalangeal joints. Each tape is untied daily and the finger moved back to its initial position.

These methods of mobilising the finger joints by splinting are only the first stage of treatment; when a moderate degree of mobility has been obtained, treatment can be carried on by massage, whirlpool

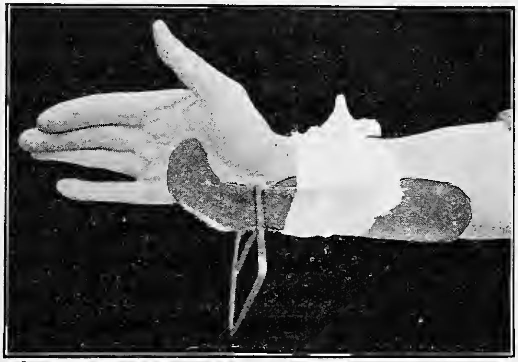

Fig. 106.—Verrall's finger-flexing splint, showing the fit of the cock-up portion in the palm and the position of the bars.

baths, passive movements, and active use. If progress is at a standstill a return to splinting methods may be advisable, and the methods thus alternating until free mobility of the hand is obtained.

Stiffness due to Changes in the Joints.—When the stiffness of the hand or any part of it is due to intra-articular changes, entirely different methods must be adopted. It is useless to treat a joint in which there is fibrous or bony ankylosis by attempting to mobilise it by splinting or by massage, or by physical means; either the joint must be left stiff, or an arthroplasty must be performed, or possibly it may be decided that an amputation is desirable. The decision as to the method must depend upon the joint affected and upon the associated injuries to other structures. In the carpo-metacarpal joint of the thumb an arthroplasty will nearly always be advisable; in the metacarpo-phalangeal joint of the thumb an arthroplasty should be performed if the tendons are intact. In this or in

the interphalangeal joint of the thumb it may, however, be advisable to leave the joint stiff, or even to convert fibrous ankylosis into a bony ankylosis by arthrodesis if the tendons have been injured. In the metacarpo-phalangeal joints of the fingers an arthroplasty may also be advisable, provided that the tendons are intact. In the interphalangeal joints arthroplasty is seldom possible, because injuries to the tendons are almost invariably present.

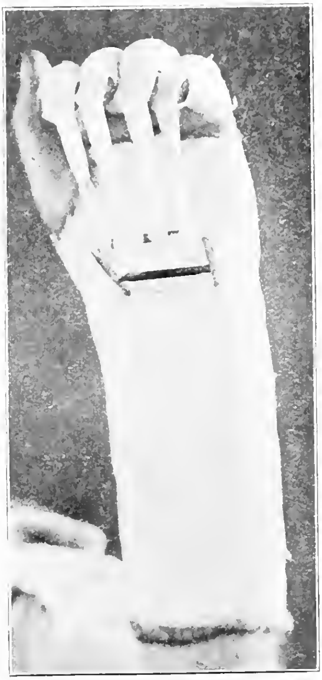

Fig. 107.—Verrall's finger-flexing splint fixed in plaster with extensions to the fingers.

Arthroplasty of these joints is carried out through a postero-lateral incision, which must avoid injury to the tendons of the interossei. The distal end of the metacarpal bone should be made convex, that of the phalanx concave. A thin flap of fascia should be inserted and an extension kept up upon the finger for three or four weeks.

Movement between the bases of the metacarpal bones is so important that it is worth attempting an arthroplasty when the bases of these bones are united. The bones should be approached from the dorsal surface, the extensor tendons being retracted; each metacarpal is then cut away from the carpus and from its neighbours. A thin shaving of bone being removed, small flaps of fibrous tissue obtained from the neighbourhood are tucked into the gaps between the bones. The hand should be fixed in a position in which the palm is well hollowed and active movement encouraged as soon as the wound is healed.

The question of amputation of individual fingers for injuries and for stiffness has been discussed in the section on amputations on the upper limb. Practically it may be said that amputation of a digit is justified when it cannot be rendered useful by any method of treatment and when it interferes with the general utility of the hand.

CHAPTER XIII

INJURIES OF NERVES OF THE UPPER LIMB

The Musculo-spiral Nerve.

The musculo-spiral nerve is injured more frequently than any other, it also recovers particularly well after suture; it may, therefore, be taken first as a good example of the methods of examination, diagnosis and treatment.

Anatomy.—The musculo-spiral nerve is a branch of the posterior cord of the brachial plexus, being derived from the fifth, sixth, and seventh cervical roots. In the lower part of the axilla it lies behind the rest of the axillary contents on the tendon of the latissimus dorsi. Immediately below the posterior axillary fold it dips between the long and inner heads of the triceps and winds around the middle third of the shaft of the humerus in the musculo-spiral groove lying beneath the aponeurotic bridge from which a part of the outer head of the triceps arises. At the junction of the middle and lower thirds of the arm it pierces the external intermuscular septum, and comes to lie deeply between the supinator longus and extensor carpi radialis longior on the outer side and the brachialis anticus on the inner side. In this position it descends towards the front of the elbow. In front of the external condyle of the humerus it divides into its terminal branches, the radial and posterior interosseous nerves.

Before the musculo-spiral nerve passes between the long and inner heads of the triceps it gives off branches to these two parts of the muscle. That to the long head enters the muscle directly, that to the inner head runs down on the internal inter-muscular septum for some distance, in close proximity to the ulnar nerve. As the nerve enters the musculo-spiral groove it gives off branches to the outer head of the triceps, one of which descends obliquely in the muscle to the back of the outer part of the elbow joint and supplies the anconeus. As the nerve is most often injured where it lies in the groove the branches to the triceps usually escape injury, but the outer head is not infrequently paralysed when the other heads are intact. The nerve to the inner head of the triceps may be mistaken for the

ulnar nerve, and the long branch to the outer head may be mistaken for the musculo-spiral nerve itself. In addition to these muscular branches a sensory branch is given off high up on the inner side, supplying the skin on the inner side of the arm over the long head of the triceps, and two external cutaneous branches arise just after the nerve pierces the external intermuscular septum. The lower of these is of considerable size and supplies the skin on the postero-external aspect of the forearm as far as the wrist. The sensory branches of the musculo-spiral do not supply any area of skin exclusively, so that in a complete division of the nerve it is difficult to ascertain that there is any sensory loss in the arm or fore-arm. After the nerve pierces the external intermuscular septum, branches are given off to the supinator longus and extensor carpi radialis longior, sometimes also a small twig to the brachialis anticus.

The radial nerve descends along the radial side of the forearm under cover of the supinator longus and lying upon the supinator brevis, pronator teres and the radius. Just above the styloid process of the radius it winds backwards under the supinator longus tendon and becomes subcutaneous. It passes superficial to the posterior annular ligament and divides into two terminal branches which furnish the main sensory supply to the posterior surface and radial side of the thumb, with the exception of the last phalanx, and to the back of the radial half of the hand and first phalanges of the index and second fingers.

The posterior interosseous nerve lies close to the radial for a short distance, giving off at this stage branches to the extensor carpi radialis brevior and supinator brevis; it then winds round the neck of the radius, passing obliquely through the supinator brevis and emerging on the back of the forearm at about the junction of the upper and middle thirds, here it lies under cover of the extensor communis digitorum upon the extensor ossis metacarpi pollicis. At this point it gives off a series of branches to the extensor communis digitorum, extensor carpi ulnaris, extensor minimi digiti and to the three extensors of the thumb and extensor indicis. Practically all these arise at the same level, but whereas the branches to the first three pass inwards directly to their muscles, those to the thumb extensors and to the extensor indicis descend in the forearm before entering the muscles they supply. For this reason in an injury to the middle of the back of the forearm the extensor carpi ulnaris and the extensor communis digitorum may remain active whilst the extensors of the thumb and index finger are paralysed. The posterior interosseous nerve after giving off these branches is reduced to a very small size, it dips under the extensor longus pollicis and runs on the

interosseous membrane to the back of the wrist, where it ends in articular filaments.

Motor Symptoms.—When the musculo-spiral nerve is interrupted the presence or absence of paralysis of the individual muscles supplied depends upon whether the injury is above or below the branches to the several muscles, always remembering that individual branches may be damaged in addition to the main trunk, and also that there may be a partial interruption of the nerve.

Complete paralysis of the triceps prevents active extension of the elbow, but such complete paralysis is rare; usually the nerve is divided in the musculo-spiral groove, the long and inner heads escape, and only the outer head is paralysed. When owing to considerable injury the affected limb is out of use it commonly hangs with the elbow

Fig. 108.—Paralysis of the musculo-spiral nerve from an injury at the level of the musculo-spiral groove.

extended by the action of gravity. Paralysis of the whole or part of the triceps may, for this reason, escape observation unless it is specially sought for.

The supinator longus is chiefly a flexor of the elbow, and should be tested by the carrying out of this movement against a resistance; the muscle can then be seen standing out contracting synergically with the biceps.

The other muscles supplied by the musculo-spiral nerve are extensors of the wrist, fingers and thumb. The extensor carpi radialis longior, extensor carpi radialis brevior, and extensor carpi ulnaris are examined by an active extension of the wrist joint. If the first two are intact and the extensor carpi ulnaris paralysed, the wrist in extending will deviate slightly to the radial side. If the extensor muscles are very weak they may be powerless to extend the wrist against gravity, but may be able to do so when the hand is held in such a way that gravity is eliminated.

The extensor communis digitorum extends only the metacarpo-phalangeal joints of the fingers. When it is paralysed the patient is still able to extend the interphalangeal joints by means of the interossei. The slip of the extensor communis to the middle finger is separate up to the middle of the forearm, it may escape paralysis when the rest of the muscle is affected by an injury of the middle of the back of the forearm.

In testing the extensors of the thumb great care must be taken to prevent the patient from flexing the wrist. Even when all three extensors are paralysed it is possible for the patient to extend the thumb by abducting it and at the same time flexing the wrist; in this way the extensor tendons are stretched and tightened, producing an extension at the metacarpo-phalangeal and interphalangeal joints which is really passive.

Anæsthesia.—The area exclusively supplied by the musculo-spiral nerve is usually very small, anæsthesia being limited to the dorsum of the cleft between the thumb and index finger; even here there may be a diminution of sensation without complete loss.

Operation.—In exploring the musculo-spiral nerve in the arm, the incision should extend from the interval between the supinator longus and brachialis anticus upwards in a curved direction along the course of the nerve. It is usually necessary to divide a part of the external head of the triceps in order to explore the musculo-spiral groove. As a rule the lower end should be sought for between the supinator longus and brachialis anticus, and the upper end at the point where it emerges between the long and inner heads of the triceps. The nerve can then be traced from these points to the damaged area in the musculo-spiral groove. When the injury is very high up it may be necessary to search for the upper end of the nerve in the axilla. A vertical incision should be made and the axillary vessels and nerves retracted inwards. The musculo-spiral nerve will be found lying behind them upon the tendon of the latissimus dorsi. When the injury is at the elbow level the musculo-spiral or posterior interosseous nerve is usually easily found between the supinator longus and brachialis anticus. If the posterior interosseous nerve is injured below the level at which it enters the supinator brevis, suture is difficult or impossible. In many cases it is not worth while to attempt it. The presence of considerable scarring, indicating much loss of substance, particularly contra-indicates an exploration of this nerve; it will be better in such cases to replace nerve suture by an operation of tendon grafting.

Splinting.—Adopting the principle of fixation of the paralysed part in such a position as will completely relax the paralysed muscles

necessitates the retention of the wrist, fingers and thumb in the fully extended position upon a long cock-up splint. If this treatment is carried out for the full period between suture of the nerve and recovery (generally five to eight months) it is apt to lead to an intractable stiffness of the metacarpo-phalangeal joints. It is a matter of common experience that failure to maintain this position does not prevent ultimate recovery in the paralysed muscles, although it may delay it. The wrist itself does not tend to become stiff, it is therefore my custom to keep the wrist extended upon a short cock-up splint for the period between suture of the nerve and recovery. When voluntary power has returned it is essential to adopt some plan for keeping the fingers and thumb habitually extended; a simple method of doing this is to attach to the cock-up splint a leather wristlet with elastics passing from its dorsal surface to leather rings around the first phalanges of the fingers and thumb. This allows the hand to be used, the fingers and thumb being actively flexed against resistance of the elastics, which pull them back into the extended position as soon as the active movement ceases. If there is a difficulty in getting a full return of active extension in the fingers and thumb a long cock-up splint with a thumb piece should be substituted and rigidly maintained in position for a few weeks at the end of the treatment. Recovery in the musculo-spiral nerve is usually good. After suture at the level of the middle of the humerus a return of power in the supinator longus and extensor carpi radialis longior may be expected in about five to seven months, and a full return of power in all the muscles in from seven to twelve months.

Tendon Grafting.—Injuries of the musculo-spiral nerve or posterior interosseous nerve in which suture is impossible are particularly suitable for treatment by tendon transplantation. When the whole nerve is paralysed the most suitable transplantation is the following: the pronator radii teres is transplanted into the extensor carpi radialis longior, the flexor carpi radialis into the extensor longus pollicis and extensor communis digitorum, the palmaris longus into the extensor ossis metacarpi pollicis and extensor brevis pollicis. If the injury is at a lower level so that the supinator longus and extensor carpi radialis longior have escaped, it is unnecessary to transplant anything into the latter muscle, and an additional extensor of the thumb may be given by using the supinator longus tendon. In injuries of the posterior interosseous nerve low down when only the extensors of the thumb and the extensor indicis are paralysed, it is possible to use a separate tendon to replace each of the thumb extensors; the best method is to transplant the palmaris longus into the extensor ossis metacarpi pollicis, the supinator longus into the extensor brevis

pollicis, and the extensor carpi radialis brevior into the extensor longus pollicis. After the successful performance of this transplantation it is difficult to determine any weakness or functional abnormality in the hand.

The Median Nerve.

Anatomy.—The median nerve arises by two heads from the inner and outer cords of the brachial plexus, the outer head derives its fibres from the sixth and seventh cervical nerves, the inner head from the eighth cervical and first dorsal. At its origin it is internal to the axillary artery; as it descends in the arm it crosses in front of the artery and at the bend of the elbow lies external. In front of the elbow it dips deeply between the pronator radii teres and the tendon of the biceps passing between the two heads of the pronator radii teres. In the upper third of the forearm it lies very deeply, being covered by the flexor sublimis digitorum, the radial head of which, as well as the pronator radii teres, must be divided or reflected in order to expose it fully. The nerve extends down the forearm between the flexor sublimis digitorum and the flexor profundus digitorum to the wrist, where it becomes superficial between the tendons of the flexor carpi radialis and the flexor indicis: passing beneath the anterior annular ligament, it enters the palm, where it divides into two terminal branches.

No branches are given off in the arm until the point where the nerve dips between the pronator radii teres and the tendon of the biceps; here it gives off first a branch to the pronator radii teres and then a series of branches to this same muscle and to the flexor carpi radialis, palmaris longus and flexor sublimis digitorum. When it lies beneath the flexor sublimis it gives off additional branches to this muscle, one at a particularly low level supplying the portion of the muscle which goes to the index finger; the anterior interosseous nerve also arises at this level. The latter gives branches to the flexor longus pollicis and to the outer half of the flexor profundus digitorum; it then runs down on the interosseous membrane, to end in front of the carpus. It supplies the pronotor quadratus as it lies on the deep surface of this muscle.

In the hand the external branch supplies twigs to the abductor pollicis, the opponens pollicis and superficial head of the flexor brevis pollicis; from the digital branch to the radial side of the index finger a twig supplies the first lumbrical, the second lumbrical is supplied from the digital branch to the cleft between the index and middle fingers, and sometimes the third lumbrical receives a branch from that between the middle and ring fingers.

The only sensory branch which arises above the wrist is the palmar cutaneous branch which passes in front of the annular ligament and supplies the radial half of the palm. The external terminal branch divides into digital nerves for the radial side of the thumb and the contiguous sides of the thumb and index finger. The internal terminal branch divides into two nerves which supply the cleft between the index and middle and middle and ring fingers. All the digital branches give off dorsal twigs which supply the dorsal surface of the last two phalanges of the fingers and of the last phalanx of the thumb.

In addition to terminal anastomoses of the sensory branches with the radial, ulnar and musculo-cutaneous nerves, the median nerve has certain communications of motor filaments with other nerves which are of clinical importance. These are—

1. A communication from the median to the musculo-cutaneous in the upper arm (see Musculo-cutaneous Nerve).

2. A communication from the musculo-cutaneous to the median below the coraco-brachialis muscle; through this filaments may pass from the musculo-cutaneous nerve to the pronator radii teres and flexor carpi radialis.

3. A communication with the ulnar in the upper part of the forearm; filaments passing between the nerves at this level may vary the proportion of the flexor profundus digitorum supplied by the median and ulnar nerves respectively.

4. A communication with the ulnar deep in the palm opposite the first interosseous space; through this the median nerve not uncommonly supplies the first palmar interosseous muscle.

Motor Symptoms.—In a complete lesion of the median nerve in the arm pronation is abolished, both the pronator muscles being paralysed. Paralysis of the flexor carpi radialis and palmaris longus does not abolish flexion of the wrist, the flexor carpi ulnaris alone can carry out this action, producing, however, a slight deviation of the hand to the ulnar side. The extensor ossis metacarpi pollicis can also flex the wrist. It is this muscle which enables the patient to flex the wrist actively when both median and ulnar nerves are completely paralysed.

The flexor sublimis digitorum is a flexor of the first interphalangeal joints, but these joints can also be flexed by the flexor profundus; therefore in paralysis of the median nerve flexion of the interphalangeal joints of the ring and little fingers is still possible. The metacarpo-phalangeal joints are flexed by the interossei, so that this movement is not interfered with in paralysis of the median nerve. Usually the ulnar supply of the flexor profundus is sufficient to enable

the middle finger to be flexed to a slight extent at the interphalangeal joints.

The flexor longus pollicis flexes the terminal joint of the thumb. The carpo-metacarpal and metacarpo-phalangeal joints are flexed by the short muscles; both these joints can be moved by the muscles supplied by the ulnar nerve. True opposition of the thumb is carried out by the median muscles, but when these are paralysed a certain amount of opposition can be carried out by the adductors.

Anæsthesia.—In paralysis of the median nerve complete loss of

FIG. 109.

FIG. 110.

Paralysis of the median nerve from an injury in the middle of the arm. In closing the grip the thumb adducts but its terminal joint does not flex, the index finger flexes only at the metacarpo-phalangeal joint, the middle finger flexes completely but not strongly, the ring and little fingers close completely and firmly.

sensation is usually limited to the flexor aspect of the index finger and to a small area of the palm at its root; over the rest of the region supplied by the nerve sensation is dulled, but not lost.

In complete interruption of the nerve the index and middle fingers are usually red, and in cold weather cyanosed. The skin becomes smooth and shiny, and cuts and burns on the anæsthetic area are not uncommon.

Operation.—Exploration of the median nerve in the arm is simple and straightforward, but at the elbow and in the upper third of the forearm a complete exposure necessitates the reflection of the

pronator radii teres from its insertion, and separation and division of the radial head of the flexor sublimis. This still leaves the nerve covered by the deep head of the pronator radii teres, and it may be necessary to divide this also. In injuries in this region the best course is to find the nerve just in front of the bend of the elbow and trace it down from this point, finding it again at the junction of the middle and lower third of the forearm and tracing it up. The pronator radii teres and flexor sublimis are then divided and reflected. Operation upon the median nerve at this level is extremely difficult, and the most careful dissection is necessary if injury to important muscular branches is to be avoided.

Splinting.—It is not necessary, or usual, to apply splints as a routine in paralysis of the median nerve; the most that is required is an application of a small splint between the thumb and index finger to keep the thumb abducted; such a splint is best made of plaster of Paris.

The Ulnar Nerve.

Anatomy.—The ulnar nerve arises from the inner cord of the brachial plexus, its fibres being derived from the eighth cervical and first dorsal nerves. At its origin it lies between the axillary artery and vein; in the upper half of the arm it is close to the inner side of the vessels, below this it pierces the internal intermuscular septum and runs down in a depression in the triceps muscle to the interval between the olecranon and the internal condyle. Passing between the two heads of the flexor carpi ulnaris it enters the forearm, where it lies along the anterior border of the flexor carpi ulnaris upon the flexor profundus digitorum, being covered by the flexor sublimis digitorum. From the middle of the forearm downwards it lies to the inner side of the ulnar vessels; it enters the palm in front of the anterior annular ligament and terminates by dividing into two branches.

The ulnar nerve gives off no branches above the elbow; as it passes between the heads of the flexor carpi ulnaris, it supplies this muscle, and immediately below this it gives two branches to the flexor profundus digitorum. In the hand the superficial part supplies the palmaris brevis and terminates in two digital branches, one of which supplies the ulnar side of the little finger, the other the cleft between the ring and little fingers; the deep part dips into the palm between the abductor minimi digiti and flexor brevis minimi digiti lying on the inner side of and below the hook of the unciform, it turns and crosses the palm with the deep palmar arch, it supplies branches to the short muscles of the little finger as it passes between

them, and as it lies deep in the palm supplies all the interossei, the inner two lumbricals, the adductors of the thumb and the deep head of the flexor brevis pollicis.

The dorsal branch leaves the nerve about two inches above the wrist, winds round the ulnar side of the wrist and supplies the ulnar part of the back of the hand.

The communications between the median and ulnar nerves have already been referred to.

Mŏtor Symptoms.—The flexor carpi ulnaris is a flexor of the wrist,

Fig. 111.

Fig. 112.

Paralysis of the ulnar nerve from an injury above the elbow. The typical injury of the ring and little fingers is apparent. In closing the grip the thumb, index and middle fingers close completely, the ring and little fingers fail to close, owing to deficient flexion at the metacarpo-phalangeal joints.

but its loss is not very noticeable as the wrist can be flexed by the flexor carpi radialis and palmaris longus, and ulnar deviation of the hand can be carried out by the extensor carpi ulnaris.

Paralysis of the ulnar part of the flexor profundus digitorum causes defective flexion in the little and ring fingers, so that the grip on the ulnar side is not closed. This is accentuated by the simultaneous paralysis of the interossei and of the third and fourth lumbricals.

The paralysis of the interossei is the most obvious sign of interruption of the ulnar nerve. Abduction and adduction of the fingers

is impossible, although slight abduction of the index finger may be carried out by the first lumbrical, and adduction of the index finger often remains because the first palmar interosseous may be supplied by the median nerve. Flexion of the metacarpo-phalangeal joints is also carried out in the main by the interossei, but the lumbricals assist in this movement. For this reason in ulnar paralysis a fair power of flexion of these joints remains in the index and middle fingers, but flexion of the metacarpo-phalangeal joints of the ring and little fingers is impossible. The characteristic deformity of ulnar paralysis consists in a hyperextension of the metacarpo-phalangeal joints of the ring and little fingers with fixed flexion of the first interphalangeal joints. This is produced by the unopposed action of the extensor communis on the former joints and of the flexor sublimis on the latter. When the ulnar nerve is divided below the level of its branches to the flexor profundus this muscle also tends to flex the interphalangeal joints of the ring and little fingers; probably for this reason the deformity of these fingers is worse when the nerve is injured below the elbow than it is when the nerve is injured in the arm. In paralysis of the ulnar nerve of long duration hyperextension of the metacarpo-phalangeal joints of the index and middle fingers may also be present.

Anæsthesia.—The loss of sensation in ulnar paralysis corresponds fairly well with the anatomical distribution of the sensory branches in the hand; it is relatively more complete than is the anæsthesia of a median paralysis. Vascular and trophic changes are usually absent.

Operation.—The ulnar nerve is very easily found in the arm, at the elbow, and at the wrist. When it is injured in the upper part of the forearm the lower end may best be found in the middle of the forearm by dissecting along the anterior border of the flexor carpi ulnaris and separating this muscle from the flexor sublimis digitorum.

As the ulnar nerve passes the elbow on the extensor aspect additional length cannot be gained by flexing the joint unless the nerve is displaced. When there is any difficulty in suturing the nerve, it is best to free it completely and to bring the ends together in front of the elbow joint. In doing this great care should be taken of the twigs supplying the flexor carpi ulnaris and flexor profundus digitorum. The loss of the former muscle is not very important, that of the flexor profundus is more important, but if it is impossible to suture the nerve without sacrificing these branches, they should be sacrificed, for a permanent paralysis of them is a much smaller disability than a permanent paralysis of the intrinsic muscles of the hand.

Splinting.—The chief object of splinting in ulnar paralysis is to prevent the fixed deformity of the fingers already alluded to. This may be done by the use of small splints on the flexor aspect of the ring and little fingers: a better method is to apply a plaster-of-Paris splint on the dorsum of the hand and fingers, moulded to the hand and keeping the wrist extended, the metacarpo-phalangeal joints at a right angle and the interphalangeal joints fully extended.

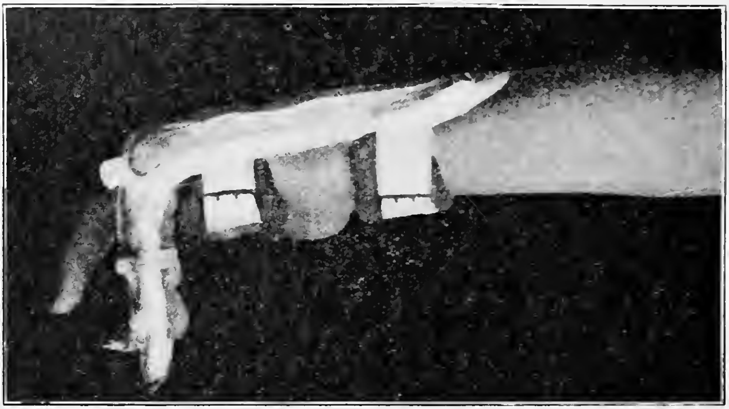

Fig. 113.—Dorsal plaster-of-Paris splint for ulnar paralysis maintaining the metacarpo-phalangeal joints in the position of right-angled flexion and the interphalangeal joints extended.

The Circumflex Nerve.

Anatomy.—The circumflex nerve is a branch of the posterior cord of the brachial plexus, being derived from the fifth and sixth cervical nerves. At its origin it lies behind the third part of the axillary artery upon the subscapularis muscle. At the lower border of this muscle it passes backwards with the posterior circumflex vessels in the space between the two teres muscles with the long head of the triceps on its inner side. It winds round the inner side of the neck of the humerus, thus reaching the posterior border of the deltoid upon its deep surface. Here it divides into terminal branches.

The upper branch winds forward around the neck of the humerus, giving off a series of branches to the fasciculi of the deltoid, small cutaneous filaments penetrating the muscle. The lower branch gives off a small twig to supply the teres minor, and then runs downwards under the posterior part of the deltoid to which it gives branches, and becomes superficial at the lower border of this muscle. The cutaneous filaments supply the skin over the lower part of the deltoid and outer side of the middle third of the arm.

Motor Symptoms.—Interruption of the circumflex nerve results in paralysis of the deltoid and a consequent complete inability to elevate the arm at the shoulder joint. The only muscle remaining which has any power to abduct the shoulder is the supra-spinatus, and the strength of this, unassisted, is insufficient. Elevation of the arm by rotation of the scapula is equally impossible because this action is dependent upon a fixation of the shoulder joint by the deltoid.

The loss of the teres minor is not noticeable.

Anæsthesia.—There is usually no area of complete anæsthesia; at the most there is a diminution of sensation over the lower part of the shoulder and adjoining part of the outer surface of the arm.

Operation.—In many cases of paralysis of the circumflex there are associated injuries to the head and neck of the humerus, and of the deltoid muscle itself. In these cases a flail shoulder results, and any attempt to suture the nerve is out of the question. Practically only in cases of injury to the nerve in the axilla by a clean bullet wound is suture possible. In most such cases there will be associated injuries to other nerves of the plexus.

The best approach to the circumflex nerve in the axilla is given by a longitudinal incision along the course of the third part of the artery; the vessels and median nerve are then exposed and retracted inwards, the circumflex nerve being looked for behind them upon the subscapularis muscle.

The treatment of flail shoulder resulting from paralysis of the deltoid, etc., will be found discussed under repair of the upper limb.

Splinting.—When the deltoid is paralysed, but the circumflex nerve is intact or has been sutured, the muscle is at a great disadvantage, because the arm hanging at the side stretches the muscle greatly. The shoulder must, therefore, be supported in the position of right-angled abduction during the period of recovery of the muscle (see Flail Shoulder).

The Musculo-cutaneous Nerve.

Anatomy.—The musculo-cutaneous nerve arises from the outer cord of the brachial plexus, its fibres being derived from the 5th and 6th cervical nerves. It is at first closely associated with the outer head of the median, which it leaves to perforate the coraco-brachialis muscle. It then passes obliquely downwards and outwards between the biceps and brachialis anticus, reaching the outer border of the biceps some distance above the elbow. The sensory terminal part of the nerve lies in close association with the cephalic vein. It perforates the deep fascia, and divides into terminal branches which

supply the skin over the outer side of the arm, anteriorly and posteriorly, as far as the wrist.

The nerve to the coraco-brachialis may be a branch of the musculo-cutaneous or may be a separate branch from the outer cord of the plexus. It is derived from the 7th cervical nerve. Whilst the musculo-cutaneous nerve lies under the biceps muscle it supplies branches to this muscle and to the brachialis anticus.

The musculo-cutaneous and median nerves present communications which are important and variable. In the first place the musculo-cutaneous may be united to the median for a considerable distance down the arm, or a part of the nerve may take this course, so that a communication passes from the median to the musculo-cutaneous in the middle of the arm. In other cases some of the fibres of the median remain with the musculo-cutaneous as far as the middle of the arm and then pass as a communication from the latter nerve to the median. This communication may explain the persistence of voluntary power in some of the median muscles when this nerve is divided in the upper part of the arm.

Motor Symptoms.—Interruption of the musculo-cutaneous nerve causes paralysis of the biceps and brachialis anticus. Flexion of the elbow can still be carried out by the supinator longus, pronator teres and other muscles attached to the external and internal condyles of the humerus. In testing for voluntary power it is therefore necessary to watch the muscles as they act and not simply to test the movement. When the biceps and brachialis anticus are paralysed flexion of the elbow in the fully supinated position is impossible. When the elbow is flexed by the accessory muscles the forearm always passes into the mid position between pronation and supination.

Anæsthesia.—The area of sensory distribution is large, but is overlapped to a considerable extent by the musculo-spiral, internal cutaneous and radial nerves, so that the area of anæsthesia is a small one on the outer border of the forearm.

Operation.—Injury to the musculo-cutaneous nerve as an isolated injury is rare. The nerve can be best explored by an incision along the inner border of the biceps.

Splinting.—During the period of recovery of a paralysis of the biceps and brachialis anticus the elbow must be maintained in the position of right-angled flexion so as to relax tension on these muscles; it is best also to keep the forearm supinated.

The use of a sling is insufficient, for every time the patient dresses or undresses the sling will be removed and the flexion relaxed. A posterior plaster-of-Paris splint, reaching from the shoulder to the middle of the back of the metacarpus is the best appliance.

Associated Paralysis of Two or more of the Brachial Nerves.

Most cases of associated paralysis of two or more of the nerves of the arm present no special difficulties. But these conditions may be of very great interest in that they may leave the action of certain muscles isolated, and thus enable us to study them. For example, in interruption of the ulnar and musculo-spiral nerves, the extensor communis digitorum is paralysed and also the interossei, so that the only muscles remaining which can extend any of the joints of the fingers are the first two lumbricals. In such cases the power of these lumbricals to extend the interphalangeal joints can be clearly seen.

Paralysis of the median and ulnar nerves present certain special features which depend upon the complete loss of the long flexors of the wrist and fingers and of the intrinsic muscles of the hand. Because of the loss of the interossei and lumbricals the hand becomes extremely flat, the transverse concavities of the palm being lost. The metacarpo-phalangeal joints become hyperextended and later the interphalangeal joints flexed. The thumb lies in the same plane as the rest of the palm, opposition being completely lost.

The wrist can still be actively flexed, the muscle possessing this power being the extensor ossis metacarpi pollicis, which crosses the joint on the palmar side of the centre of movement. A pseudo-flexion of the fingers with opposition of the thumb is also possible. The extensors of the wrist act strongly, hyperextending this joint; this puts tension upon the long flexor tendons and brings the fingers into a position of flexion and adducts the thumb. It may be possible for a patient thus to close the thumb and first finger together and to grasp a light object.

The Brachial Plexus.

The brachial plexus consists of the intercommunications of the 5th, 6th, 7th, and 8th cervical nerves, and the first dorsal nerve between their exit from the spinal canal and their termination in the lower part of the axilla by division into their final branches.

In cases of injury to the nerves in this region the diagnosis of the exact level and nature of the injury may be very difficult; it must depend upon an exact knowledge of the usual anatomical arrangement and upon an understanding of the levels at which the branches arise.

The usual arrangement of the plexus is set out in the following table, adapted from Quain's Anatomy and in the diagram (Fig. 114).

		C. V.	C. VI.	C. VII.	C. VIII.	D. I.
	Branches from Roots.					
In substance of Scalene Muscles	To Longus Colli	+ ?	+ ?	+ ?	+ ?	
	,, Scaleni	+	+	?		
	,, Phrenic	?				
	,, Rhomboids	+				
	Posterior thoracic I. & II.	+	+			
In posterior triangle of neck	,, ,, III.			+ ?		
	Branches from Trunks.					
	Upper Trunk.					
	Suprascapular	+	+ ?			
	To Subclavius	+	?			
	Branches from Cords.					
	Outer Cord.					
In axilla . .	External Anterior Thoracic	+ ?	+	+		
	To Coraco-brachialis			+		
	Musculo-cutaneous	+	+			
	Outer head of Median		+	+		
	Inner Cord.					
	Internal Anterior Thoracic				+	+
	Internal Cutaneous				+	+
	Lesser Internal Cutaneous					+
	Ulnar			?	+	+
	Inner head of Median			?	+	+
	Posterior Cord.					
	Upper Subscapular	+	+			
	Middle Subscapular		?	+	?	
	Lower Subscapular	+ ?	+			
	Circumflex	+	+ ?			
	Musculo-spiral	?	+	+	+	

In the above table + signifies that the nerve receives fibres from the spinal root in whose column it is placed, + ? signifies that it usually receives fibres from this root but not invariably, ? signifies that fibres from this root are less common.

The Nerve to the Rhomboids arises in the substance of the scalenus medius in common with the highest root of the posterior thoracic nerve; it passes through the scalenus medius muscle and then downwards to the posterior superior angle of the scapula, lying under cover of the levator anguli scapulæ, which it supplies. It then runs downwards under the rhomboid muscles, supplying twigs to them.

The Posterior Thoracic Nerve arises by three roots from the 5th, 6th and 7th cervical nerves. The upper two roots pierce the scalenus medius muscle and unite in the substance or on the surface of that muscle. The third root passes in front of this muscle and joins the other two opposite the first rib. The nerve runs downwards behind the brachial plexus and first part of the axillary artery, upon the superficial surface of the serratus muscle, supplying twigs to this muscle.

The Posterior Scapular Nerve arises from the trunk formed by the 5th and 6th cervical nerves. It passes outwards and backwards beneath the trapezius and omo-hyoid muscles to the upper border of the scapula, where it passes through the suprascapular notch into the supraspinous fossa, thence through the great scapular notch into the infraspinous fossa. It supplies the supraspinatus and infraspinatus muscles.

The Nerve to the Subclavius is derived from the same trunk and passes behind the clavicle to the subclavius muscle.

The External Anterior Thoracic Nerve arises from the outer cord immediately below the clavicle; it passes in front of the axillary

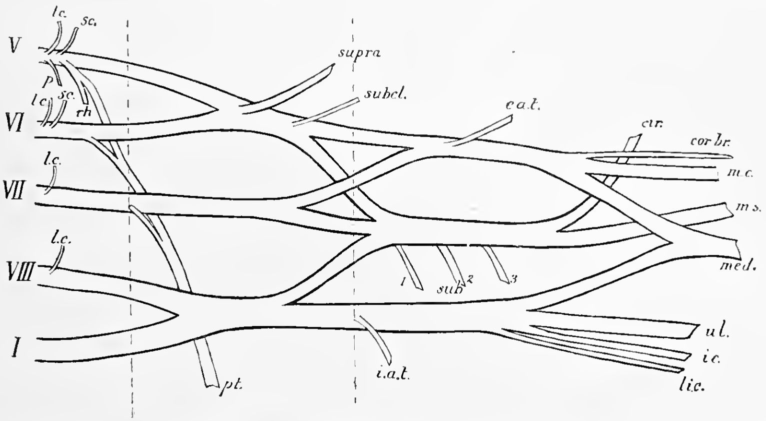

FIG. 114.—Diagram of the brachial plexus: *l.c.* Nerves to longus colli, *sc.* nerves to scaleni, *p.* branch to phrenic nerve, *rh.* nerve to rhomboids, *p.t.* posterior throacic nerve, *supra.* supra-scapular nerve, *subcl.* nerve to subclavius, *e.a.t.* external anterior thoracic nerve, *i.a.t.* internal anterior thoracic nerve, *sub.* 1, 2, 3, first, second and third subscapular nerves, *cir.* circumflex nerve, *cor.br.* nerve to coraco-brachialis, *m.c.* musculo-cutaneous nerve, *m.s.* musculo-spiral nerve, *med.* median nerve, *ul.* ulnar nerve, *i.c.* internal cutaneous nerve, *l.i.c.* lesser internal cutaneous nerve.

artery, communicates with the internal anterior thoracic, and ends in the pectoralis major muscle.

The Internal Anterior Thoracic Nerve arises from the inner cord and comes forward between the axillary artery and vein. It forms a plexiform loop in front of the first part of the axillary artery with the communication from the external anterior thoracic nerve, and from this branches are given off to both pectoral muscles. The terminal branches of the two anterior thoracic nerves as they enter the pectoral muscles are in close association with the branches of the axillary artery which supply those muscles (superior thoracic and acromio-thoracic).

The Three Subscapular Nerves are derived from the posterior cord

of the plexus. The uppermost arises high up in the axilla and ends in the upper part of the subscapularis muscle. The middle or long subscapular arises in the middle of the axilla and descends with the subscapular artery to end in the latissimus dorsi muscle. The third arises immediately below the second and ends in the teres major.

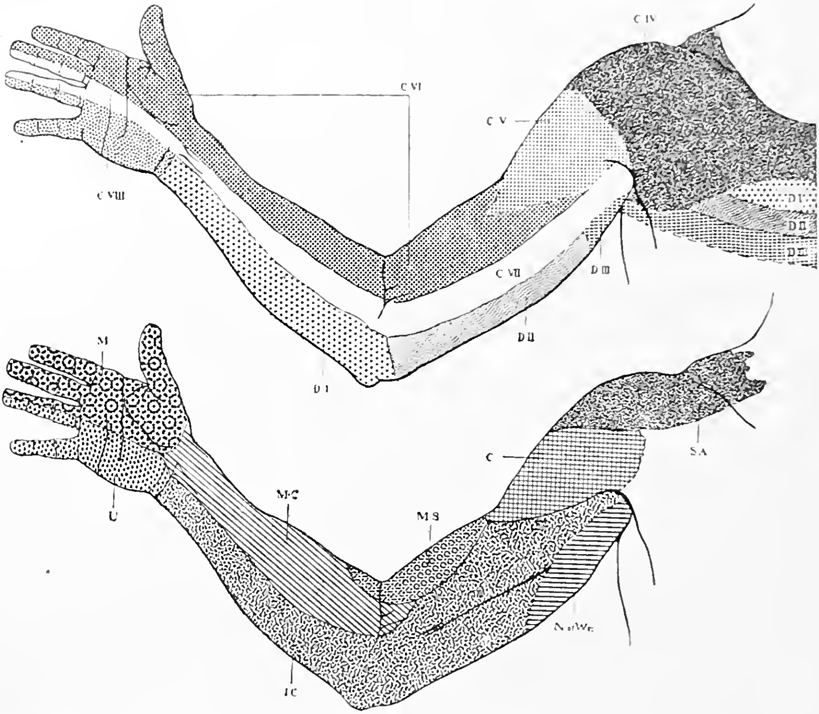

FIG. 115.—Diagram of cutaneous distribution of the roots entering into the brachial plexus and of the branches of the plexus. (Prepared by Dr. Grainger Stewart at the Military Orthopædic Hospital.)

The areas supplied by the roots are indicated by C. IV., C. V., C. VI., C. VII., C. VIII., D. I., D. II., D. III.

S.A. supra-acromial branches of the cervical plexus; C. circumflex; M.S. musculo-spiral; M.C. musculo-cutaneous; M. median; U. ulnar; I.C. internal cutaneous; N. of W. lesser internal cutaneous; R. radial.

The rest of the nerves of the plexus have already been described except the internal cutaneous and lesser internal cutaneous, which are purely cutaneous and not of much surgical importance. The former, however, sometimes gives rise to pain when it is injured without being divided. It may then be necessary to explore and divide it. It is also sometimes used for transplantation to replace a nerve which has been damaged so that it cannot be sutured. When

it is necessary to expose it for either of these reasons it may be found in the axilla in close association with the ulnar nerve, lying rather superficial to this. Lower in the arm it follows the course of the basilic vein.

The Diagnosis of Injuries of the Brachial Plexus.—As has already been said, the diagnosis of lesions of the brachial plexus is difficult

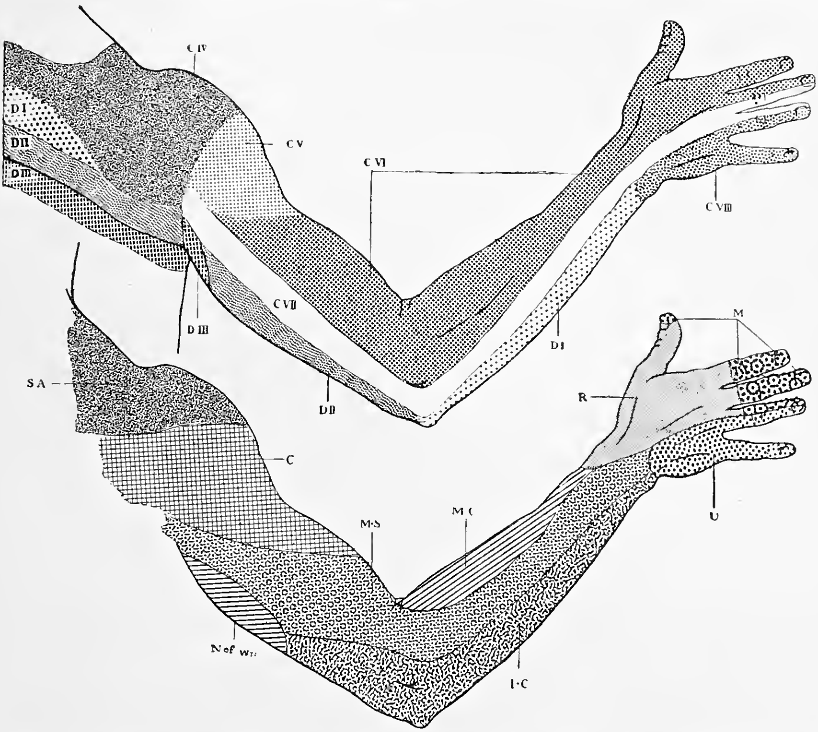

FIG. 116.—Diagram of cutaneous distribution of the roots entering into the brachial plexus and of the branches of the plexus. (Prepared by Dr. Grainger Stewart at the Military Orthopædic Hospital.)

The areas supplied by the roots are indicated by C. IV., C. V., C. VI., C. VII., C. VIII., D. I., D. II., D. III.

S.A. supra-acromial branches of the cervical plexus; C. circumflex; M.S. musculo-spiral; M.C. musculo-cutaneous; M. median; U. ulnar; I.C. internal cutaneous; N. of W. lesser internal cutaneous; R. radial.

because of the complex arrangement of the nerves. It is rendered additionally difficult because a missile passing through a region where there are so many important nerves is very apt to cause considerable bruising and effusion, so that a temporary or partial interruption of some of the nerves from this cause may be present in addition to a complete division of other nerves. For this reason a lesion of the plexus should, as a rule, be carefully studied and

watched over a period of weeks or months before surgical intervention is undertaken. It may be said that the initial paralysis is nearly always much greater than that due to the actual nerve division, so that with time and appropriate mechanical and electrical treatment the condition will improve, the paralysis due to nerve division only becoming clear after a considerable interval. The advisability of waiting is further indicated by the fact that exploration of the plexus, particularly at special levels, is by no means easy, and that if one of the trunks has been divided it may be difficult or impossible to suture it.

For clinical purposes lesions of the plexus may be divided into those in which the roots are affected, those in which the main trunks above the clavicle are affected, those in which the cords in the axilla are affected, and those in which the terminal branches are affected.

The lesions of the roots can be worked out by comparing the distribution of the paralysis with the table already given and the area of anæsthesia, or of diminished sensation with the charts (Figs. 115 and 116). Interruption of the fifth and sixth roots yields a characteristic paralysis (Erb Duchenne) in which the deltoid, biceps, brachialis anticus, supinator longus, supra and infra spinati, subscapularis and teres major are completely, and the triceps and rest of the extensor group and pectoralis major are partially paralysed. If the injury is within the scalene muscles, the serratus magnus, levator anguli scapulæ and rhomboids will also be affected. A complete injury to the upper trunk will give the same loss with the exception of the last-named muscles.

A complete lesion of the lower two roots (8th cervical and 1st dorsal) or of the trunk formed by the union of these gives a second characteristic paralysis, in which the flexors of the fingers, flexor carpi ulnaris and intrinsics of the hand are affected. The paralysis corresponds nearly to a combined paralysis of the median and ulnar nerves, but the flexor carpi radialis escapes.

A complete lesion of the 7th cervical yields a picture extremely like that of musculo-spiral paralysis. The triceps is, however, only partly paralysed and the supinator longus escapes.

An injury of the cords in the axilla causes a paralysis corresponding to the nerves into which the affected cord or cords divides: thus, if the posterior cord is affected the paralysis is a combination of musculo-spiral and circumflex paralysis. In addition, a clue as to the level of the lesion may be given by the affection of branches which arise in the axilla, such as the subscapular nerves.

In the case of the inner and outer cords one head only of the median may be affected, so that it is necessary to say a few words

as to the fibres conveyed to the median by these two heads. The outer head of the nerve probably conveys fibres which supply the pronator radii teres and flexor carpi radialis, and possibly some to the muscles of the thenar eminence. The inner head conveys fibres which supply the flexor communis and flexor profundus digitorum.

It must be remembered that in the upper part of the axilla, all three cords, external, posterior and internal, lie above the axillary artery, so that any or all of them may be injured without the artery being touched.

Operation upon the Brachial Plexus.—As already said, exploration of the brachial plexus is not to be undertaken lightly. As a rule, every case should be studied and watched carefully and the operation only undertaken when it becomes clear that there is a definite injury to some root or cord which is not showing signs of recovery. When an operation is performed it is important that it should be carried out in such a way that there is no risk of doing further injury to the plexus.

In the supra-clavicular part of the plexus exposure through a vertical incision is comparatively easy, provided that the scarring is not great. The only structures which interfere with the dissection are the omo-hyoid muscle and the transversalis colli and suprascapular vessels; these must be divided if necessary. The spinal accessory nerve and cervical nerves to the trapezius should be above the level of the incision, and the external jugular vein anterior to it, though a tributary entering the latter from behind may require division. The descending cutaneous branches of the cervical plexus may be cut, but this is of no importance. As they run in the direction of the incision, however, they will probably escape.

In the upper part of the axilla exposure of the cords of the plexus is much more difficult. A good method is to carry an incision from the middle of the clavicle along the interval between the pectoralis major and deltoid as far as the insertion of the former muscle, then curving it inwards across this insertion. The attachment of the pectoralis major to the humerus is then lifted upon the finger and split into its superficial and deep halves. The superficial half is divided close to the humerus, the deep half about an inch and a half internal to this point (this mode of division of a muscle renders subsequent suture much easier and more secure). The muscle can then be reflected inwards and downwards; the external anterior thoracic nerve will be found entering its deep surface and forms a guide to the outer cord of the plexus. The whole plexus can then be exposed by dividing the upper part of the costo-coracoid membrane and the insertion of the pectoralis minor. In the upper part of the axilla

the inner cord is somewhat inaccessible; it is a mistake to search for it here on the inner side of the artery. It can best be found by defining the outer cord and the posterior cord which lies behind it, then by separating these two, the inner cord will come into view lying on the inner side of the outer cord and at a slightly deeper level. By exposing in this way injury to branches is avoided, as no branches arise from the upper surface of the cords in the axilla.

When it is necessary to expose the plexus more fully the clavicle must be divided. This is best done by splitting it longitudinally with a motor saw and dividing the upper and lower halves so as to leave an overlap of an inch. Subsequent suture is thus facilitated.

CHAPTER XIV

REPAIR IN THE LOWER LIMB

Stiffness and Ankylosis of the Hip Joint.

Injuries in the neighbourhood of the hip may affect the sub sequent mobility of the joint, first, through the production of periarticular adhesions and contractures; secondly, by the production of fibrous adhesions inside the disorganised joint; and thirdly, by the production of a bony ankylosis. In addition to these classes a functional adduction of the hip is not unusual; it is probably derived from the adducted position which is assumed when the patient commences to walk on crutches. This condition has been mentioned and its treatment described in the consideration of functional deformities.

In most cases of fracture of the neck or trochanteric region of the femur considerable stiffness of the joint remains, due to intra-articular, or periarticular adhesions. In these cases, provided that the fracture is united with good alignment, the only treatment possible is that of massage and manipulation and suchlike physical methods.

Periarticular Adhesions.—An important impairment of the movement of the hip joint by periarticular scarring is comparatively rare. In most cases of scarring around the hip extension remains full, and sufficient flexion for ordinary purposes is easily secured. Only in amputation stumps is a fixed flexion deformity in the hip at all common.

When extension of the hip is limited the disability may be considerable, because the flexed position of the hip renders the limb unstable and necessitates greatly increased muscular exertion in standing and walking. As a rule manipulations will correct flexion deformity; but these, if they are to be efficient, must be carried out by the method advised for the treatment of flexion at the hip joint in an amputation stump. If the patient is simply laid upon his back and the thigh pressed down upon the couch, the result is not to extend the hip, but to produce a lordosis in the lumbar spine; in order to extend the hip it is necessary to fix the lumbar spine and

pelvis. This is most easily done by flexing the opposite hip fully, then pressure upon the thigh upon the affected side can be used to force extension at the hip joint.

In very rare cases the resistance to extension may be so great that it is impossible to correct the deformity by daily forced movements; the obvious treatment will then be to cut down upon and divide the structures which impede full extension. This, however, necessitates a very considerable operation, for in these obstinate cases it will probably be found that the scarring extends through the tensor fasciæ femoris, sartorius, rectus femoris, ilio-psoas, and even the anterior part of the capsule of the hip joint. In a recent case in which the hip was flexed about 50°, and in which there was a large scar in front of the joint, I corrected the flexion deformity by performing an osteotomy immediately beneath the trochanters, considering that this was an easier method than the division of all the scarred structures. The functional result was excellent.

Abduction, adduction, and internal or external rotation may any of them arise as the result of scarring around the hip. In a case recently shown to me by Major Joyce, an injury in the region of the obturator foramen had been followed by persistent external rotation at the hip, due, probably, to spasm and contracture of the obturator muscles. At my suggestion Major Joyce corrected the deformity by dividing the small external rotators at their insertion into the great trochanter and digital fossa, the limb was fixed in plaster in the internally rotated position for a month, and the result was excellent, the patient returning to duty.

Fibrous Ankylosis.—Fibrous ankylosis of the hip is comparatively uncommon in military surgery. In civil practice it is frequent and troublesome, because the joint possesses practically no useful mobility and has a constant tendency to become deformed into the flexed and adducted position, producing much apparant shortening and consequent disablement in walking.

When the hip with fibrous ankylosis remains in a good position it requires no treatment. When it shows a constant tendency to become adducted and flexed the only possible procedure is to perform a limited excision of the joint by the posterior route, the object being to secure a mobile joint which, though weaker than the joint before excision, will not have the tendency to become deformed.

Bony Ankylosis.—Bony ankylosis of the hip is a common result of penetrating wounds in which sepsis has supervened. The necessity for treatment will depend upon the position in which the joint is ankylosed, and upon whether both joints are affected. If ankylosis has taken place with the hip extended, or flexed not more than 30°,

and if the joint is slightly abducted and rotated neither in nor out, then the position may be considered to be perfect and to require no treatment. If the joint is ankylosed in a greatly flexed, or adducted, or rotated position, it will be necessary to correct this deformity by osteotomy. The object of the operation will be to bring the limb into the position of 25° of flexion with the patella pointing straight forwards, and neither abduction nor adduction unless the limb is shortened. If the limb is short it should be abducted to such an extent as will leave the two limbs apparently equal in length when they are placed parallel. If the shortening is very great (over one and a half or two inches) it is inadvisable to compensate for this fully by abducting, as the tilt of the pelvis thus produced will be uncomfortable.

The best form of osteotomy is that which is carried out obliquely, through the great trochanter. An incision is made on the outer side down on to the great trochanter, the muscles are stripped from the front and back of the bone, and an aneurysm needle or hook can be passed obliquely downwards and inwards into the notch above the small trochanter; this gives the line for division of the bone. As a rule this line is parallel with Poupart's ligament. An osteotome is then entered half an inch below the great trochanter, and the bone chiselled through along the line that has been laid out. The densest bone is that last divided on the inner side. It is, therefore, necessary to complete the division with the osteotome, and not to trust to fracturing this hard bone. Some surgeons prefer to carry out this osteotomy with an Adams' saw. When the bone has been divided the thigh is pulled into the required position and fixed in plaster of Paris from the foot to the pelvis, the opposite thigh being included. A proper correction of the deformity and fixation in plaster is greatly facilitated by the use of a well-designed extension table, such as the Hawley table.

The exact site of an osteotomy for the correction of a hip deformity must depend, to some extent, upon the nature of the previous injury. It is desirable to perform the operation at a little distance away from the original trouble, particularly if there has been much septic infection. For the correction of flexion and adduction it is essential to perform the osteotomy high up in the femur; even the subtrochanteric osteotomy of Gant, although it corrects the deformity, leaves an ugly angulation of the femur. Rotations inwards or outwards may, however, be corrected at a lower level. It is possible to correct an internal rotation of the hip by performing a supracondylar osteotomy, and rotating the knee and leg out at this point.

Excision of the hip performed with the object of securing a mobile joint should be reserved for—

1. Cases in which both hips are ankylosed. In these cases the better hip should be left ankylosed; it is possible to correct this by osteotomy if necessary. The weaker or more severely injured hip should be selected for excision. When, however, one limb has been shortened considerably, the hip of this side should be left ankylosed, the hip on the longer side being excised.

2. Cases of fibrous ankylosis in which the hip persistently tends to flex and adduct; and—

3. Exceptional cases of bony ankylosis, in which it appears impossible to correct the position by a simple osteotomy. Practically these cases include only those in which the hip is ankylosed in a dislocated position.

The best route for excision of the hip is the posterior one. Langenbeck's incision may be used, or a V-shaped incision with the point downwards over the base of the great trochanter. The great trochanter should be chiselled off and turned up with the muscles inserted into it. The amount of bone removed from the head of the femur and acetabulum must depend upon the conditions present in the individual case. In fibrous ankylosis it is only necessary to remove a moderate amount of bone, to round off the stump of the femur, and clean out the acetabulum; the great trochanter may then be pegged down to its original situation. In cases of bony ankylosis it is necessary to remove a considerable amount of bone. If a large gap between the stump of the femur and the acetabulum can be easily secured the trochanter may be replaced in its proper situation. If, however, it seems likely that the cut surfaces of the femur and acetabulum will come into contact, then it will be better to peg or nail the great trochanter against the cut surface of the acetabulum, so that the stump of the femur may rest against the outer surface of the trochanter and not against raw bone. The result of this procedure is to secure mobility, but to leave a far weaker joint.

After excision of the hip the limb must be kept well abducted and extended; fixation upon a double Thomas frame or upon a net bed is the best method. When the wound is healed and walking is commenced, a caliper splint should be fitted and worn from six to twelve months.

Flail Hip Joint.

A flail condition of the hip joint results from removal of the head of the femur, either at the time of the injury or subsequently. The stump of the femur, being unable to engage in the acetabulum,

rides up on to the dorsum ilii whenever the weight of the body is thrown upon the limb. This flail condition is to some extent preventable if the hip is kept well abducted after the head of the bone has been excised; a moderate stability will result in all cases except those in which a very large section of the bone has been lost. When a flail condition of the joint is established it should be treated by fitting a caliper splint with a close-fitting ring, so that the weight is transmitted directly from the pelvis to the ground and the upward excursion of the stump of the femur is thus prevented. The wearing of such a splint for a year will often restore sufficient stability to enable the patient to walk without support.

Chronic Osteo-myelitis of the Femur.

In the femur more often than in any other bone compound fractures which have become septic leave a chronic osteo-myelitis, with septic tracks, and cavities containing sequestra. The sinuses leading to these cavities may persist for years, for the sequestra are too large to escape; and often, even after they are removed, cavities lined with granulations remain which may persist for an indefinite period, because their walls are too hard to fall in and close, and there is no healthy tissue around from which the contents of the cavity can become organised. For the cure of these cases of chronic osteo-myelitis of the femur a radical operation, such as that described in Chapter II, is essential.

The whole of the shaft of the femur can be best approached by an incision along the outer side; through such an incision the bone can be explored from the top of the great trochanter to the external condyle. The only part of the bone which may require exploration by a different route is the internal condyle and internal supracondylar ridge; these can be safely explored through a vertical incision extending upwards from the adductor tubercle.

It is essential in operating thus upon the femur to cut away the scar tissue freely, and to free a flap of muscle so that it can fall in and close any cavity that remains in the bone. Along the outer side of the femur the vastus externus is available for this purpose; over the internal condyle and supracondylar ridge the lowest part of the vastus internus can be used.

Mal-union of the Femur.

Mal-union of the femur is frequent, and the deformity may be complicated; it may be analysed into the following elements :—

(*a*) Shortening, by overlapping.
(*b*) Angulation, with a convexity outwards.
(*c*) Angulation, with a convexity backwards.
(*d*) Rotation of the lower fragment inwards or outwards.

The correction of mal-union, either by osteotomy or by reconstruction of the fracture, necessitates a long period of treatment for the new fracture produced. The operation, particularly reconstruction of the fracture, is a severe one, and the shock considerable; before such a severe operation is undertaken it is very necessary to consider whether the disablement is really due to the mal-union, or whether possibly it is due to associated conditions.

When the deformity consists of shortening only, it can seldom be justifiable to operate, for the shortening, as such, does not constitute a great disability. In order that it may be corrected and the limb lengthened the fracture must be reconstructed, and the soft parts must be stretched either by a very powerful extension or by the leverage action produced by angulating the fragments against each other. This operation is an extremely severe one, justified only by the promise of a great functional improvement in the patient's limb. When the shortening is accompanied by an angulation of the fragments, it is usually necessary to reconstruct the fracture in order to correct this, and the correction of the angulation is essential. Therefore, we may say that for simple shortening the operation of reconstruction of the fracture is seldom justifiable; for shortening with angulation it is not only justifiable, but desirable. Rotation of the lower fragment inwards or outwards is easily corrected by a simple osteotomy carried out close above the condyles, and, if possible, well away from the site of the original fracture.

Perhaps the most frequent form of mal-union of the femur is that in which the lower fragment forms an angle with the upper, which is convex posteriorly; this results in an apparent hyperextension of the knee which has most disabling results (Fig. 12): it is essential that such a deformity be corrected. As a rule this can only be adequately done by reconstructing the original fracture and replacing the lower fragment in correct alignment.

In all cases reconstruction of a fracture of the femur carries with it a very great risk of recrudescence of sepsis. It is exceedingly common in an old septic compound fracture to find some small dormant focus of suppuration; if this is opened during the operation, or if its walls are simply split open by force and the septic material escapes into the tissues, it may produce severe reinfection. For this reason a very close watch should be kept for any such focus

during the operation. If any cavity lined with granulations is found, its walls should be chiselled away completely, and the whole wound should be treated with BIPP before being sutured. The liability to such septic complications is one of the important reasons for preferring to correct mal-union of the femur by a simple osteotomy through healthy bone, whenever this is possible.

After the correction of a mal-united femur it is best to fix the entire limb, including the pelvis, in plaster of Paris; this, however, will not be efficient in cases in which it is necessary to keep up an extension on the lower fragment. In such cases it is better to fix the limb upon a Thomas's knee splint with the knee slightly bent and extension of the leg, the splint being slung upon a Balkan frame, or some such contrivance. The usual period (ten to twelve weeks) must be allowed for union of the new fracture, and the patient should then be made to walk in a caliper splint for two months or longer, according to the nature of the union.

Delayed Union and Non-union of the Femur.

Delayed union of the femur is frequent; non-union is very rare. Delayed union may be due to mal-position, or to sepsis, with necrosis of the bone between the fractured ends, or it may be due to a loss of bone which has left a considerable gap. Such a gap will often fill up with new bone formed from periosteum which has remained continuous. When there is loss of substance in the femur, extension may be kept up for eight to ten weeks in the hope that new bone will form. If, however, at the end of this time there is no evidence of union either clinically or in an X-ray photograph, the extension should be relaxed so that the ends of the fragments can come into contact, and union, with shortening, thus take place.

When union is delayed as a result either of sepsis or of mal-position, or of loss of bone, the treatment must be—

1. The removal of sequestra from between the ends of the bone by a free exposure. These sequestra will almost certainly have separated at the end of ten weeks from the time of the injury.

2. The replacement of the fractured ends in proper alignment by free incision and exposure.

3. Fixation upon a Thomas's splint, with only sufficient extension to keep the fragments in line, avoiding such extension as will distract the fractured ends from each other. This fixation should be kept up for ten to twelve weeks, and during that period the area of the fracture should be treated daily by passive congestion.

4. If union is still incomplete, but a true pseudarthrosis or flail

condition absent, union will probably take place if the limb is fixed upon a caliper splint and the patient allowed to walk upon it.

We may consider that there is true non-union of the femur—

(i) When from the beginning, in spite of good position, without loss of bone and without sepsis, no sign of union occurs. In such a case there is almost certainly some muscle tissue interposed between the fragments.

(ii) When treatment by the elimination of sepsis, fixation for ten to twelve weeks without extension and the subsequent use of the limb on a caliper splint for three months leaves the fracture still ununited.

In these cases an open operation is required. The bone should be exposed by a long incision on the outer side, the ends freed and refreshed, all intermediate scar tissue being removed. When the ends have been got into good position either by extension or by angulation they are best fixed by an insertion of a long and stout inlay graft, taken from the tibia of the opposite side, or a plate may be used, provided that asepsis is certain. The limb must be put up upon a Thomas's splint with extension and treated like an ordinary fracture of the femur.

Derangement of the Knee Joint.

Persistent weakness of the knee following upon a more or less severe simple injury is extremely common. The symptoms are—

1. Pain most often referred to the inner side or to a point beneath the patellar tendon.

2. A feeling of weakness, so that the knee cannot be relied upon, particularly in walking upon a slope or up or down stairs.

3. The knee may actually give way when the weight is on it in the flexed position, so that the patient falls down.

4. In some cases, when the knee gives way it locks, the patient being unable to extend the knee until he or someone else has manipulated and twisted it.

5. Attacks of swelling occur sometimes after the knee has given way, or locked, sometimes after exercise, independent of such accidents.

In these cases there is a tendency on the part of surgeons to make the uniform diagnosis of injury to the internal semi-lunar cartilage. This, however, is only one of a number of possibilities. Before arriving at the diagnosis a careful investigation upon the following lines is necessary :—

(*a*) The history must be carefully taken. The position in which the knee gives way, the occurrence of true locking and of an effusion into the joint being specially noted.

(*b*) The range of movement of the knee should be tested, extension should be compared with that of the opposite limb, and flexion should be tested by trying the kneeling trunk backward falling exercise, as follows : The patient kneels on both knees, with hands on hips and thighs and trunk vertical; he then allows the trunk and thighs to fall backwards, keeping them in the same straight line; this movement flexes the knee, with the quadriceps muscle very completely stretched. Slight differences in the range of flexion of the knee which are not evident by any other method of examination are thus demonstrable. During this test the patient will often complain of pain, or of a feeling of tension upon the inner side of the front of the knee.

(*c*) Abnormal mobility of the joint must be looked for. The knee may hyperextend as compared with the opposite side, or there may be lateral mobility in the fully extended position, or the patient may be able to displace the tibia forwards or backwards on the femur when the knee is slightly flexed.

(*d*) The size and power of the quadriceps muscle should be compared with the opposite side. The muscle must be put into action by making the patient forcibly extend the knee. The vastus internus is represented by the rounded muscular mass seen in front of the lower part of the internal surface of the thigh, and should be particularly noticed. It will often be found to be evidently smaller upon the affected side.

(*e*) The knee should be palpated for any tender spots or abnormal prominences. Sometimes a tender spot will be found on the inner side, over the joint line, in the region of the anterior part of the internal semi-lunar cartilage; sometimes the attachments of the internal lateral ligament are tender, and often there is a tender point over the internal condyle of the femur, a little above the joint line and anterior to the internal lateral ligament. This is a common site for peri-articular adhesions. In the rare cases of slipping of the external semi-lunar cartilage the whole cartilage may jump outwards when the knee is flexed, an audible snap occurring, and the cartilage being palpable in its new position.

(*f*) The joint should be X-rayed, and such changes as lipping of the edges of the bone, the presence of bony loose bodies, or of irregularities in the femur or tibia should be noted.

The sesamoid bone in one of the tendons behind the knee may be mistaken for a loose body. If there is any doubt, the knee should be X-rayed first in the extended and then in the flexed position. If the shadow is due to a sesamoid bone it will stand away from the joint when the knee is flexed. The following two cases show the necessity for careful X-ray examination in cases of derangement of the knee joint.

A man aged twenty-seven had suffered from pain and weakness in the left knee for thirteen years. This had become worse during the last two or three years, probably as the result of slipping upon a greasy floor. A day's work produced severe pain, sufficient to prevent him sleeping. Before seeing me the condition had been diagnosed as due to a loose internal semilunar cartilage, and a knee-cage had been fitted without benefit. Upon examination, some tenderness was found on the inner side of the head of the tibia. An X-ray photograph showed the existence of a small cartilage-capped exostosis at this point. This was removed, and the patient lost his symptoms completely.

The second patient was a man aged thirty-seven, who injured his right knee whilst playing Rugby football, the knee having been very forcibly and suddenly flexed. Scott's dressing was applied and continued for ten days, by which time the swelling had subsided, but the knee could not be extended fully or flexed as far as a right angle. On the fifteenth day after the injury the knee was examined under chloroform, some adhesions being broken down. Massage was then given, but his movement did not improve, and a second examination under chloroform was carried out eight days after the first. The knee was flexed fully and the ankle tied to the buttock. The patient found that the pain produced by this was so severe that he undid the bandage. Two days later the masseur came to the conclusion that there was a displaced cartilage, and advised the patient to consult a well-known bone-setter. The latter had an anæsthetic administered and replaced the cartilage. For three weeks after this massage and exercises were used; during this time the knee extended fully, but did not flex freely. At the end of three weeks the bone-setter broke down adhesions under another anæsthetic and twice flexed the knee fully, after the patient had recovered consciousness. The pain was severe after this, but massage and exercises, including forcible flexion, were continued for three more weeks. During this time the amount of flexion allowed steadily diminished. One month after the last anæsthetic the patient returned to the bone-setter, who expressed himself as dissatisfied, and enquired into the presence of any tuberculous history and

ordered an X-ray photograph. As the latter did not in his opinion show the presence of tuberculous disease, he advised the continuation of massage and forcible movements.

It was now over three months from the time of the injury and

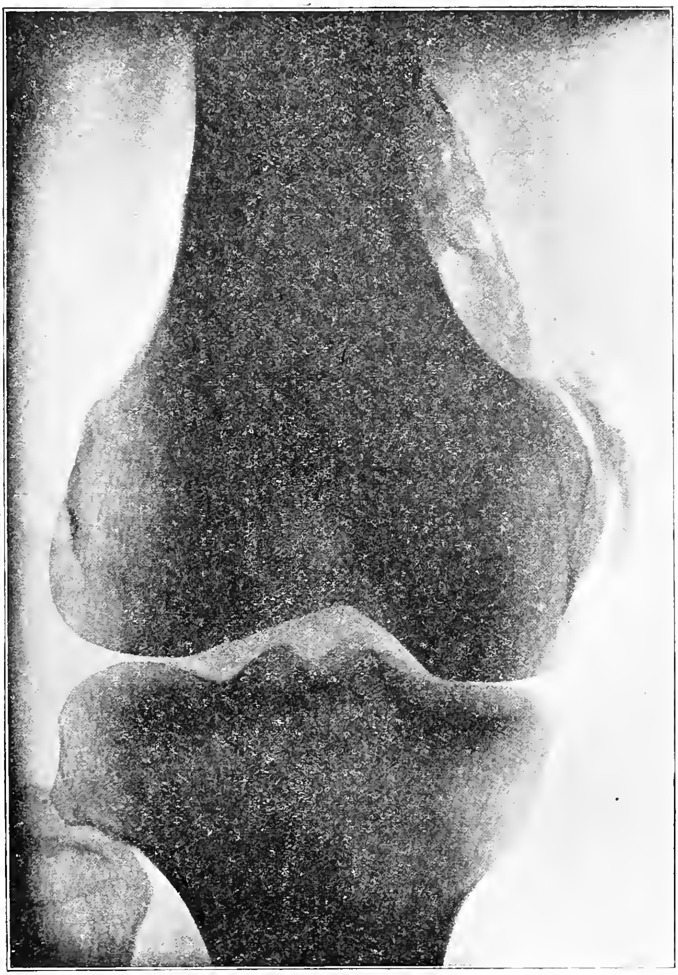

Fig. 117.—Myositis ossificans in the vastus internus and ossification of the inner part of the capsule of the knee joint (see text).

nine weeks from the time when the bone-setter was consulted. The patient now consulted another medical man, who ordered complete rest with hot poultices and passive congestion. After ten days this was altered to rest, with the application of iodine. At the time that this treatment was started the knee was much swollen, painful and

practically immobile. The rest resulted in the diminution of the pain and swelling without appreciably affecting the mobility of the joint.

The patient had previously suffered from an injury to the semilunar cartilage of the left knee, which had slipped out on several occasions, always as the result of tripping with his foot everted. This cartilage was removed by a surgeon, and there was no after trouble in this knee. In the patient's opinion the right knee had never slipped in the way that the left used to do.

This patient was first seen by me six months after the injury. The knee was then stiff in an extended position, only about 10° of flexion being permitted. There was no enlargement of the joint itself, but there was a tender swelling over the external condyle of the femur which extended up the inner side of the shaft of the bone for about three inches. A new X-ray photograph had been taken, and this showed two bony plates over the internal condyle, and another mass of bone attached to the supracondylar ridge and to the shaft of the femur above it. An examination of the old X-ray photograph, taken two and a half months after the injury, showed the same condition, except that the masses of bone were smaller. It was evident that the original injury had included a strain of the internal lateral ligament, with some tearing of the attachment to the vastus internus muscle. This resulted in a process of myositis ossificans, which had undoubtedly been made much worse by the repeated attempts to secure movement. The patient was now treated by fixation of the knee in a straight splint. Six months later the swelling had diminished and 30° of flexion was allowed. After a further six months the movement had increased to 45°, and an X-ray photograph showed the masses of bone smaller and better defined. It will probably be necessary to remove this bone, and subsequently to increase the range of movement by slow flexion in a rack splint.

Clinical Types.—As a result of the investigation carried out in this way, cases of derangement of the knee joint may be divided into the following clinical types.

1. *Simple Periarticular Adhesions.*—In this there is limitation of full flexion, some wasting of the quadriceps muscle, particularly of the vastus internus, and slight tenderness, chiefly over the internal condyle of the femur. There is no abnormal mobility of the joint, and the X-ray shows no changes. The history is usually that there has been an initial injury followed by a period of rest, then after this the knee has either given way without locking, or has felt weak and tired after exercise, or perhaps has swollen whenever considerable exercise has been taken.

In these cases the appropriate treatment is, first, the administration of an anæsthetic, the knee being put through its full range of flexion and extension, and the tibia rotated outwards when the limb is flexed. If only slight adhesions are heard to crack no bandage need be applied; if, however, the adhesions found have been considerable, a firm compression bandage may be put on to prevent the formation of effusion into the joint. This compression bandage is put on in the following way: A layer of cotton wool one inch thick is wrapped round the limb from the middle of the thigh to the middle of the calf; a flannel or domette bandage is then applied as tightly as possible, commencing over the middle of the joint and working downwards and upwards to within an inch of the end of the cotton-wool, leaving, however, an inch of cotton-wool uncovered. A firm, elastic compression is thus kept up which prevents the joint from swelling. Small movements of the knee inside the bandage produce slight variations in pressure, which have the effect of massage upon the joint, helping to cause absorption of any fluid which has already been formed.

The day following the anæsthetic the knee is massaged, put through its full range of movements, and the patient made to carry out active exercises. The two most important exercises are—

(*a*) Kneeling trunk backward falling as already described.
(*b*) Tiptoe double knee bend and stretch, *i. e.* standing with hands on hips, tiptoeing, and whilst on tiptoe bending both knees slowly, until he is sitting upon his heels, then slowly stretching the knees again, keeping all the while on tiptoe and only lowering the heels when the knees are fully extended.

The object of these exercises is, first, to induce the patient to carry out full flexion and extension movements of his knee, and secondly, to use the quadriceps muscle actively in extending the knee and raising the body. This treatment is sufficient in itself to produce a complete cure. It may, however, with advantage be assisted by electrical stimulation of the quadriceps, as presently to be described. When the movements of the knee are unrestricted and the muscle is as strong as on the other side, the patient will be cured.

2. *Quadriceps Insufficiency.*—There is no limitation of movement, in fact, no physical signs of any sort, except a wasting of the quadriceps muscle, particularly of the vastus internus. The most characteristic point in the history is that the knee gives way when it is in the flexed position, but does not lock. There may be an occasional effusion into the joint.

The treatment of these cases is designed to strengthen the quadriceps muscle, and particularly the vastus internus. The latter muscle is not very much concerned in the actual extension of the knee joint; when it contracts it draws the patella inwards and steadies the inner side of the knee; its chief use is in balancing the joint, particularly in positions in which the whole weight of the body comes upon the slightly flexed knee. It is for this reason that an insufficiency of this part of the quadriceps leads to a weakness of the knee, so that the joint is liable to give way when it is in a flexed position. In order to strengthen the vastus internus muscle by active exercises these must be carried out in such a way as to make the balance difficult, for the difficulty of balancing at once brings the vastus internus into play. The value of such exercises as "tiptoe double knee bend and stretch" lies in the introduction into them of this element of balancing, which enables such exercises to be utilised for toning up the vastus internus muscle.

Electrical treatment of the quadriceps muscle as introduced by Bristow is of great assistance in the treatment of these cases of quadriceps insufficiency. The treatment consists in direct stimulation (1) at the common quadriceps point, and (2) of the vastus internus, by means of a surging faradic current which produces alternate contraction and relaxation of the muscle. which is thus made to carry out a definite amount of work without the exertion of the will power of the patient.

3. *Hypermobility.*—In cases in which there is lateral mobility of the joint or abnormal mobility in other directions. there must have been an injury of one of the important ligaments. which is either ruptured or overstretched. The most frequent forms of hypermobility are—

(*a*) Mobility of the tibia outwards when the knee is extended, due to a strain of the internal lateral ligament.

(*b*) A displacement of the tibia backwards or forwards in relation to the femur when the knee is flexed, due to an injury to the crucial ligaments.

(*c*) Hyperextension of the knee, due to an injury to the posterior ligaments or perhaps to a fracture of the spine of the tibia. The latter injury will be evident in an X-ray photograph.

In these cases of abnormal mobility the first essential in the treatment is to support the knee in such a way that the abnormal movement can never occur. This is done by the application of a knee-cage. The ordinary light knee-cage, often known as Marsh's knee-splint, is not efficient. The best method of making a

knee-cage is the following: A plaster-of-Paris cast of the limb is taken from the lower end of the calf to above the middle of the thigh; moulded leather pieces are made on this cast to fit closely around the thigh from its middle to the level of the condyles, and round the leg from immediately below the knee to beyond the middle of the calf. These are connected by lateral steels, jointed opposite the centre of rotation of the knee joint, and the outside steel is carried on and inserted into a socket in the heel of the boot. Stops can be fixed in the steel joints to prevent movement beyond any desired range; for example, if the knee hyperextends, a stop can be inserted which prevents full extension. Whilst this knee-cage is being worn it is desirable to carry out electrical treatment to strengthen the quadriceps. In many cases of strain of the lateral or crucial ligaments, the wearing of such a knee-cage for six to twelve months will enable the ligaments to adapt themselves so that the abnormal mobility diminishes or disappears.

4. *Injuries of the Semilunar Cartilage.*—The characteristic of a true injury of the internal semilunar cartilage is the giving way of the knee when it is in the flexed and externally rotated position, with locking of the joint so that some manipulation must be carried out before the knee can be fully extended. Usually such an accident is followed by an effusion into the joint. The pain is characteristically over the anterior end of the cartilage, that is, exactly in the joint line.

In many cases, in which the history appears definitely to point to an injury of the internal semilunar cartilage, it will be found that flexion of the knee is slightly limited and the quadriceps muscle is wasted. It is worth while to treat these patients by mobilisation of the knee, under an anæsthetic, followed by exercises and electrical treatment of the muscle. Often restoration of full movement and muscular power will prevent the recurrence of symptoms, and will thus do away with the necessity for an operation. Only when this preliminary treatment has been tried, or when movement is already quite full and the quadriceps equal in strength to that of the other side, or when the cartilage is blocking the extension of the joint and cannot be moved by manipulation under an anæsthetic should an operation for excision of the cartilage be performed.

The operation of excision of the internal semilunar cartilage is a serious one, not to be undertaken lightly, and its results are not nearly as good as is commonly believed. It should be carried out with the strictest aseptic precautions. The opening into the joint should be made close to the patella and not carried too far inwards, for if the internal lateral ligament is cut a permanent weakness of

the joint remains. It is only necessary to remove the anterior half or two-thirds of the cartilage, and the greatest possible care must be taken to avoid injury to the synovial membrane and cartilage of the joint surfaces.

As soon as the wound is healed, massage, exercises and electrical treatment should be commenced and kept up until the movements of the joint are quite full and the muscles strong.

5. *Loose Body.*—A loose body in the knee joint makes the knee give way, usually without any complete locking; the accident is followed by an effusion into the joint. The symptoms are similar to those of simple quadriceps insufficiency, and the presence of a loose body can only be guessed at unless an X-ray demonstrates its presence. The treatment is the removal of the loose body, followed by massage, exercises and electrical treatment.

6. *Osteo-arthritis.*—An early osteo-arthritic condition may give rise to almost any of the above symptoms. The X-ray appearances must be the guide in arriving at the diagnosis. When this demonstrates the presence of slight bony changes unaccompanied by any active inflammatory symptoms, it is worth while to treat the joint by mobilisation, exercises and electrical methods. When, however, the occurrences of effusion or puffiness of the joint indicate that the process is active, the knee requires rest in the extended position until all active signs have ceased.

Gunshot Wounds of the Knee Joint.

The treatment of gunshot wounds of the knee joint by early excision and suture has been extremely successful. In wounds that have healed in this way, and in simple bullet wounds which have healed without treatment, it is not always easy to determine the correct time for commencing movement, the method of securing mobility and the range of movement at which we should aim. Much depends upon the presence or absence of an injury to the bone. In all cases the knee should be kept upon a splint until the wound is healed, and until all swelling has subsided. Early movement is dangerous; in spite of the absence of any external evidence of infection, there is a strong possibility of latent sepsis in these wounds, and the slight damage that may be done by movement is very likely to produce a sudden inflammatory reaction which may end in suppuration in the joint. Possibly, by delaying movement, the eventual cure is retarded, but this loss of time is much more than counterbalanced by the very real risk of a septic infection of the joint. In a case which has followed an aseptic course and in which there is no

fracture, as soon as the wound is healed and the swelling has subsided the patient may be allowed to walk upon the limb. In order to give him confidence, a back splint should be kept on whilst he is walking for the first week. Massage and gentle passive movement may be carried out, and an eventual complete return of mobility is to be expected.

In cases in which there has been a fracture into the joint it is better to wait for six weeks or longer, in order to allow time for union of the fracture, then massage and passive movements may be carried out and the patient allowed to walk. In these cases there will almost certainly be a permanent diminution in the range of movement. When progress is slow, attempts to extend the range of mobility may be made upon the principles described below for the treatment of intra-articular adhesions in the joint.

In cases in which there has been a mild septic infection of the wound it is necessary to wait until all symptoms have subsided and until the wound is soundly healed before even considering the possibility of moving the joint. Any early attempts are extremely likely to lead to an acute septic infection of the joint. When the wound has healed, an X-ray photograph should be taken with a view to determining whether the joint surfaces are intact. If the surfaces of the femur and tibia are smooth and even, and the joint interval clear, some mobility of the joint may be expected, and treatment to secure this by massage and passive movement may be carefully started. If, however, the X-ray photograph shows a roughening and irregularity of the joint surfaces, it is quite useless to attempt to secure movement. It will be better at once to inform the patient that the best result that he can have is a stiff knee joint, and accordingly to immobilise the joint and to wait for ankylosis.

Stiffness and Ankylosis of the Knee Joint.

Limitation of movement of the knee joint may be due to simple injuries or to gunshot wounds of the joint, and also to injuries of the thigh or leg, particularly to compound fractures. The following general classification of cases of stiffness of the knee may be made :—

1. Simple periarticular adhesions, which have already been described under derangement of the joint.

2. More severe periarticular adhesions, with scarring of the thigh muscles, such as occurs in a simple fracture of the lower part of the femur.

3. Very severe scarring in the muscles, periarticular structures and capsule of the joint, such as occurs in infected compound fracture of the femur.

4. Myositis ossificans in the thigh muscles, as already described.

5. Scarring of the capsule, with slight intra-articular adhesions, as in simple aseptic gunshot wounds of the joint, without fracture.

6. Alteration in the surface of the bone, due to a fracture into the joint.

7. Intra-articular fibrous ankylosis, due usually to an infection of the joint.

8. Bony ankylosis.

9. Alteration of the alignment of the femur or tibia after a fracture.

Treatment.—In the first two of these classes a complete return to the normal may be expected. In the very slight cases, as already described, immediately full mobilisation may be carried out under an anæsthetic, and following up by massage, passive movement and exercises. In the more severe cases full movement of the joint under an anæsthetic may result in considerable immediate damage by the tearing of scarred tissue and the formation of a hæmatoma. If this occurs the probability is that it will be necessary to delay further mobilisation until the effusion has been absorbed, so that it will be found that rapid mobilisation has delayed matters instead of assisting them. It is only possible to determine exactly how much force it is worth while applying in breaking down adhesions by individual experience. Up to a certain point, the stretching or rupture of adhesions under an anæsthetic assists the restoration of movement. Beyond that point the damage done and the effusion inevitably produced delays subsequent treatment.

In very severe scarring and in cases of fracture into the joint it is seldom advisable to carry out immediate rapid mobilisation. In the first of these groups, great force is required to stretch or tear the adhesions, and this force may quite probably rupture the quadriceps muscle or fracture the patella before the adhesions themselves will stretch. Even if these accidents do not occur, the production of a hæmatoma is almost certain; if this forms outside the joint in the neighbourhood of an old compound fracture it will almost certainly become infected, starting a fresh period of suppuration. In the second class of case, when there is a fracture into the joint, a rapid mobilisation will tear the intra-articular adhesions and grind the surfaces of the bone upon each other. An effusion of blood into the joint is almost certain to occur, and the pain produced by pressure of the irregular bone surfaces upon each other will induce a muscular spasm which prevents increased movement. Rapid mobilisation is also undesirable in cases of gunshot wound of the joint without bone involvement. In these progress may be slow,

and the surgeon may be tempted to administer an anæsthetic and put the joint through its full range of movement. This procedure will break down intra-articular adhesions and possibly rupture a scar in the capsule, doing quite unjustifiable damage, which delays the return of mobility.

In these three classes of case the best method of hurrying the return of movement is by flexing the knee slowly by continuous pressure. A MacIntyre splint, jointed opposite the centre of rotation of the knee, is fixed in plaster of Paris to the thigh and leg, the foot being enclosed in the lower piece of plaster; the screw of the MacIntyre splint is then slowly turned day by day and the knee progressively flexed. When flexion has been carried as far as possible, the knee should be left at this degree of flexion for two to three weeks and the splint then removed. The movement thus secured will probably disappear in the course of a week, but massage and passive movement will restore it in the course of the next few weeks.

This slow method of flexing the knee, gradually stretches the adhesions without inducing any excessive inflammatory reaction and without causing sufficient damage to produce a hæmatoma. There is usually considerable pain whilst the knee is being flexed, and there may be a temporary swelling of the joint after the plaster has been removed. The immediate result is to alter the position of the knee rather than to increase the range of movement; that is, if there was a 30° range of movement from 150° to 180°, then flexing the knee to a right angle will probably leave the knee mobile through the range of 90° to 120°. It is only as the result of subsequent massage and exercises that the full range of 90° to 180° will come.

Another method of dealing with these cases is to administer an anæsthetic, and to flex the knee to a moderate degree, fixing it, either on a splint or in plaster of Paris, in the new position. In this way considerable damage is done and an inflammatory reaction occurs. Fixation for two or three weeks allows this inflammation to subside, and massage and exercises will then probably secure the additional range of movement through which the joint has been stretched. This method is an older one than that previously described and has practically been superseded by it.

The critical point in mobilisation of the knee is the position of flexion to a right angle. As soon as the patient has attained this degree of movement he can kneel upon the knee and assist further movement by the pressure of his own weight. Practically, when the movement exceeds the right angle, it is possible for an intelligent patient to secure the remainder of the movement of his joint by his own efforts.

In cases of close intra-articular fibrous ankylosis, or bony ankylosis, and in some cases of fracture into the joint, it is useless to attempt to secure mobility, the bone surfaces have been destroyed or roughened and the cartilage eroded to such an extent that a freely mobile joint is out of the question. As in the knee joint, stability in the extended position is more important than anything else, these cases should be fixed with the knee in the fully extended position, either by an external splint or by the operation of excision.

If an X-ray photograph shows that there is a small intra-articular lesion affecting only one part of the joint, where the surface of the bone is roughened or irregular, and where presumably adhesions exist, it may be worth while to open the joint, divide the adhesions, smooth down the bone and cover it with a transplanted layer of fat. The full operation of arthroplasty of the knee joint is only in the experimental stage, it is suitable only for cases of intra-articular lesions without bony ankylosis and with a small range of painful mobility. In the present stage of our knowledge it is not possible to promise that this operation will leave a mobile knee, in which the movement is painless and free, and in which the joint is stable. For this reason most surgeons will prefer to advise an excision of the knee, as the firm ankylosis which results gives a limb which is functionally useful, painless and stable.

In some cases the knee joint is stiff in a flexed position; this deformity must be corrected. If the stiffness is due to periarticular changes, extension can almost always be secured by the exertion of force, whilst the patient is under an anæsthetic. The hamstring muscles, the ilio-tibial band, and the attachment of the gastrocnemii may all hinder extension. They can be stretched with comparative ease, except the biceps and ilio-tibial band; these by holding the outer side of the tibia and fibula backwards produce a posterior displacement of the head of the tibia, and in order that this may not persist when the knee is extended it is often advisable to divide these two structures. The biceps tendon should be divided by an open operation; the ilio-tibial bend may be divided subcutaneously. If it is feared that forcible straightening of the knee under an anæsthetic will produce too much damage and possibly start a recrudescence of old sepsis, Turner's splint may be used to secure a gradual extension of the knee; this consists of metal pieces, which are incorporated in plaster of Paris around leg and thigh, and which are united at the knee by a joint placed eccentrically in front of the joint. By screwing up a rack the knee is gradually extended, and, because of the eccentric position of the joint, the leg and thigh are distracted slightly from each other.

In close fibrous ankylosis and in bony ankylosis of the knee in a flexed position, the best treatment is an immediate excision, so that bony ankylosis in the fully extended position results. When flexion is not too great, a formal excision of the ordinary type can be carried out and the joint thus straightened with the loss of one to one and a half inches in the length of the limb. If, however, flexion is extreme, it may not be possible to straighten the knee by excision without sacrificing several inches of bone; in this case a preliminary operation may be performed, a fine osteotome being introduced on either side of the joint and the connection between the tibia and femur thus divided. The knee may then be partially straightened by force and a Turner's splint applied to increase the correction by gradual means, then, when only 30° or so of flexion results, an ordinary excision of the joint may be carried out.

Chronic Osteomyelitis of the Tibia.

Chronic osteomyelitis of the tibia following compound fracture of the bone presents three special difficulties in treatment.

1. The sequestra consist of very dense bone and separate with extreme slowness; it is usually necessary to wait at least four months for separation to be complete.

2. A large section of the bone is subcutaneous; this renders exposure very easy, but makes it difficult to find muscle or other tissue with which any cavity in the bone can be filled. In the upper half of the bone the soleus muscle can be utilised if the cavity remains upon the inner or posterior aspect of the bone. Small flaps can be secured from the tibialis anticus muscle to fill cavities in the anterior part of the bone, but it is not possible to use much of this muscle without running the risk of injury to the anterior tibial nerve. In the lower half of the bone no muscle is available for use for filling a cavity.

3. When there is much loss of skin, which has left adherent scars and ulcers, it is difficult to excise these and to cover in the raw area. These cavities are most common in the upper end of the bone and in the lower end close to the malleolus. The routine method described in Chapter II should be used, all scars and ulcers being excised. When there is difficulty in covering the area a flap should be turned down from above, as there is usually a certain amount of skin to spare in the region of the knee. A cavity in the upper part of the bone should, if possible, be laid open on the inner side, as close to the inner border as possible. It usually happens that the cavity takes the form of a longitudinal cleft in the bone which contains sequestra and granulation tissue. When such a cleft has been laid well open and cleaned

out, it may be found possible to chisel through either the internal border or the anterior border of the bone at the extremities at this cleft, and to break this border of the bone inwards so that it falls into the cleft and helps to close it. When the internal border can be utilised in this way it is often possible to fill the remainder of the cavity with a small flap taken from the soleus muscle. In the lower half of the bone a thorough bevelling down of the edges of the cavity must be carried out, as no muscle is available for insertion. If a cavity in the lower part of the bone remains which cannot be bevelled down or filled, it should be laid open thoroughly and drained, and subsequently filled with a free transplant of fat as advised by Rutherford Morrison. If it is impossible to cover the tibia with sound skin, the granulating area must be left and a subsequent attempt made to cover this with a pedicle flap from the opposite thigh or calf, the legs being fixed in a cross-legged position.

Chronic osteomyelitis of the fibula gives little trouble, because in cases of necrosis of this bone it is possible to resect a length of the shaft completely without any subsequent disability.

Mal-union of the Tibia and Fibula.

The most important forms of mal-union of the tibia and fibula are—

1. In the upper end—
   - (*a*) Angulation inwards, producing a genu valgum.
   - (*b*) Angulation forwards, producing flexion of the knee.
   - (*c*) Angulation backwards, producing hyperextension of the knee.
2. In the shaft—
   - (*a*) Angulation backwards, so that the front of the tibia is concave.
   - (*b*) Less often, angulation inwards or outwards.
   - (*c*) Rotation of the lower fragment inwards, so that the foot points in.

Any of these, unless it is very severe in degree, can be corrected by a simple osteotomy. Osteotomy of the upper end of the tibia is difficult because of the width of the bone; it is, therefore, sometimes better to correct such a deformity as a knock-knee, due to an old fracture of the tibia by an osteotomy of the lower end of the femur. Flexion of the knee, or hyperextension of the knee, due to mal-union of the tibia, may be corrected, if necessary, by an osteotomy of the shaft of the bone a little below the fracture. Often,

however, it is unnecessary to correct these deformities. The common conditions of concavity of the front of the tibia and internal rotation of the lower fragment are easily corrected by a simple osteotomy either above or below the line of fracture. Mal-union of the tibia is commonly associated with some deformity of the ankle, most often talipes equinus; this should be corrected by elongation of the tendo Achillis and wrenching at the same time as the osteotomy is performed.

FIG. 118.—Compound fracture of the tibia united with much shortening and with internal rotation of the lower fragment. There was a chronic ulcer over the tibia. Treated by (1) excision of the ulcer and suture; (2) subcutaneous osteotomy below the area of the fracture.

A mal-union of a Pott's fracture has already been described with its treatment by a complete reconstruction of the fracture and wrenching of the feet into a good position.

Non-union of the Tibia and Fibula.

Delayed union of the tibia is not rare, it is due either to necrosis between bone ends, or to a loss of bone so that the extremities of the fragments lie apart and are prevented from coming into contact by the presence of an intact fibula. When sepsis is present, the first step is the removal of sequestra and the cleaning of the area of the fracture. When a gap of a half to three quarters of an inch exists and the fibula keeps up this separation, an oblique osteotomy of the latter bone, so that the fragments can slide upon each other with the subsequent application of a walking splint, will usually bring about union.

In those cases of true non-union in which a considerable section of the shaft of the tibia is lost, a massive graft taken from the crest of the opposite tibia may be inserted and securely inlaid into the upper and lower fragments. Figs. 25 to 29 illustrate the replacement of a gap of several inches in the tibia by a graft ten inches long taken

from the opposite side. The patient was subsequently able to walk upon the limb without external support.

Deformities of the Ankle and Foot.

After any injury of the lower limb we should aim at securing a foot that is as far as possible natural in shape, and that possesses active and passive mobility in all directions to the natural extent. Such a result may be precluded by the nature of the injury itself, but apart from this it is very common to find some loss of mobility, due to shortening of one or more tendons, not only in cases of injury below the knee and in damage to the sciatic nerve, but even in cases of injury to the thigh or hip, uncomplicated by any nerve injury. In these cases the deformity is one of posture, and should have been avoided.

All the deformities of the ankle and foot may be classed together generally as talipes. It will be as well first to consider the anatomical varieties of talipes and their causation, then passing on to the treatment of injuries of the lower limb from the point of view of the prevention of talipes, and finally considering the treatment of these deformities when they are established.

Varieties of Talipes.—Talipes may be fixed or postural. It is fixed when the foot cannot be put through its normal range of movement by an externally applied force; for example, when the tendo Achillis is so tight that the foot will not dorsiflex beyond the right angle there is a fixed talipes equinus.

It is postural when passive mobility is full but active mobility in some direction is absent or insufficient; for example, if the tendo Achillis is divided or over long active plantar flexion is defective and there is a postural talipes calcaneus. Further, in talipes which is the result of an injury, there may be a loss of bone or an alteration in the shape of the bones, so that the malformed foot is not simply held in a position of contraction but is anatomically altered in shape. The differentiation of cases of foot deformity into three groups: (1) Fixed talipes, (2) Postural talipes, and (3) Cases of anatomical malformation of the foot, is an essential preliminary to treatment.

The complicated movements of the ankle and tarsus may be simply classified as follows:—

(*a*) Dorsal flexion at the ankle to an angle of 30° beyond the right angle.
(*b*) Plantar flexion to an angle of 60° beyond the right angle.
(*c*) Inversion and adduction occurring chiefly at the subastragaloid and mid-tarsal joints (varus movement).
(*d*) Eversion and abduction at the same joints (valgus movement).

Although plantar flexion at the ankle joint only extends to about 60° beyond the right-angled position, the fore part of the foot can be further plantar flexed at the mid-tarsal joint, often sufficiently to bring the dorsum of the foot into a straight line with the front of the leg. In this movement the arch of the foot is increased.

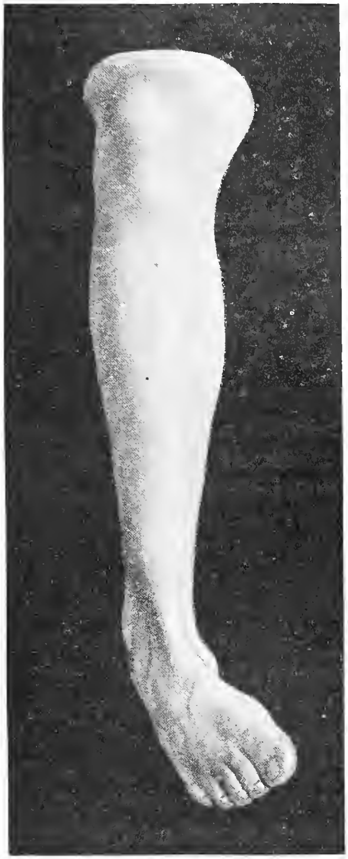

FIG. 119.—Varus movement of the foot (inversion and adduction).

FIG. 120.—Valgus movement of the foot (eversion and abduction).

When the foot is in a position of fixed deformity corresponding to these movements, the following varieties of talipes are present :—

(*a*) *Talipes Equinus*, when the foot cannot be dorsiflexed to its full degree. When dorsiflexion is limited to the right angle, the condition is often called right-angled talipes.

(*b*) *Talipes Calcaneus*, when the foot cannot be plantar flexed to its full degree.

(c) *Talipes Varus*, when the foot is adducted and inverted, and the opposite movement is impossible.

(d) *Talipes Valgus*, when the foot is everted and abducted, the opposite movement being impossible.

The deformity may be more complicated. For example, inversion and adduction may be associated with deficient dorsiflexion, the deformity being then a talipes equino-varus. The usual combinations are—

(e) *Talipes Equino-varus.*
(f) *Talipes Calcaneo-valgus.*
(g) *Talipes Equino-valgus.*

Finally there may be an alteration in the longitudinal arch of the foot. If this is flattened the condition is—

(h) *Pes Planus.*

If it is increased, the condition is—

(i) *Pes Cavus.*

The latter condition consists essentially in a plantar flexion and inversion of the fore part of the foot at the mid-tarsal joint. It is often associated with the different varieties of talipes, the conditions being named—

(j) *Talipes Equino-cavus.*
(k) *Talipes Equino-varo-cavus.*
(l) *Talipes Calcaneo-cavus*, etc.

The Causation of Talipes.— causation of postural talipes is simple. It is the loss of one or more of the important muscles of the leg, either by paralysis or by division of its tendon, or by destruc- of its substance. For example, paralysis of the external popliteal nerve, affecting the tibialis anticus, the extensor communis digitorum, the extensor longus hallucis and the peronei, causes a talipes equino-varus, the posterior tibial muscles being unopposed. Division of the tendo Achillis or over-lengthening of that tendon gives rise to a talipes calcaneus. Destruction of the peronei causes a postural talipes varus. In these cases prevention is impossible, but if care is not taken the postural deformity may pass into a fixed one, the unopposed muscles becoming contracted. It is important that this should be prevented by the proper use of splints from the first, so that when the wounds have healed and the appropriate surgical treatment by nerve suture, tendon suture, etc., is possible, it may not be necessary to correct a fixed deformity by an additional surgical

procedure. It may be thought that the correction, for example, of a fixed talipes equinus by tenotomy of the tendo Achillis is a simple matter, but even so simple and safe an operation leaves a certain amount of permanent weakness in the ankle movement.

The causation of fixed deformities is more complicated, contraction of unopposed muscles being only one of the causes.

1. *Bone Injury.*—In the first place, a fixed talipes may be due to an injury of the tibia or fibula or of the tarsus, with mal-union or with loss of substance. A mal-united Potts' fracture, with persistent eversion and abduction at the site of fracture, gives rise to a severe talipes valgus; a subastragaloid dislocation with displacement of the foot outwards does the same; loss of the whole astragalus usually causes talipes varus, loss of parts of the tarsus may cause almost any deformity.

2. *Ankylosis of the Ankle or Tarsal Joints* in a sense must inevitably produce a talipes, for the movements of the foot must be restricted. When ankylosis is probable because of injury to or infection of these joints, our aim should be to maintain the foot as a whole in that position which will be most useful for standing and walking. The best position will be described in the next section.

3. *Shortening of Muscles by Scarring.*—An extensive injury to a muscle produces fibrosis in its substance and consequent shortening. A simple injury, which heals aseptically, tends in this way to produce much less shortening than does one which has been infected. Whilst a wound of the calf is healing there is often a persistent spasm of the gastrocnemius and soleus, due to irritation, and this condition may persist even after the wound has healed, particularly if the posterior tibial nerve or one of its branches is irritated. This condition of talipes equinus from spasm may only be distinguishable from a fixed talipes due to fibrosis by examination whilst the patient is under an anæsthetic. If in such a case the spasm relaxes under anæsthesia, the foot should be at once dorsiflexed to just over the right angle and fixed in plaster of Paris. If the condition is found to be fixed and not due to spasm, it should be corrected by lengthening the tendo Achillis forthwith.

4. *Adhesion of Muscles or Tendons in the Neighbourhood of Wounds* prevents full movement in the direction in which these muscles are put upon the stretch. For example, if the anterior tibial muscles are adherent, plantar flexion of the foot is deficient.

5. *Shortening of Muscles, the Opponents of which have been Paralysed, Divided, or Destroyed*—that is, the production of a fixed talipes from a postural one. This prolific cause of fixed talipes has been already alluded to. The very real danger of its production makes

it essential that in all cases of paralysis of, or injury to, the muscles of the leg, the foot should be most carefully splinted from the first. A special class of case requires mention. There can be little doubt that in some cases of trench foot there exists a neuritis affecting the posterior tibial and plantar nerves. This is often followed by the supervention of a pes cavus, which may be severe in degree and accompanied by a clawing of the toes, due probably to a paresis of the interossei, and corresponding to the *main en griffe* which follows the affection of the intrinsic muscles of the hand. When the pes

Fig. 121.—Pes cavus with clawing of the toes, resulting from trench foot.

cavus is severe it may be accompanied by an apparent talipes equinus, but usually, if the position of the heel is carefully noted, it will be found that the os calcis bears its normal relation to the ankle and the dropping of the foot takes place at the mid tarsal joint, so that if the pes cavus can be fully corrected the equinus disappears. It is important to recognise this, as it is a mistake to lengthen the tendo Achillis in these cases, the correction should be made by flattening the sole.

6. *Shortening of Muscles as the Result of the Maintenance of the Foot in one Fixed Position during the Healing of a Wound or the Consolidation of a Fracture.*—For example, in a fracture of the tibia, if the foot

is kept in a plantar flexed position during the period required for union, a fixed talipes equinus not uncommonly results. The production of such a deformity in injuries below the knee is not uncommon in civil practice, but in military surgery the risk of producing this type of talipes is much greater, and it extends to injuries of any part of the limb up to the hip. Possibly this risk is due to the severity of the injuries, more probably it is due to the frequence of septic complications. As in the case of the hand, the œdema of the limb so often found below a compound fracture may be evidence of quiet septic infection, resulting in subsequent organisation of the effusion and fibrosis. The latter affects the muscles, and the calf muscles being the most powerful, and being aided by the dependent position of the foot, become shortened, producing a fixed talipes equinus. This form of talipes is sometimes called talipes decubitus, the idea being that it is purely postural in origin. Experience has shown that the healthy foot may be left in the plantar flexed position for long periods without contraction resulting, so that a simple postural origin is improbable. But in all cases of injury to the lower limb met with in war surgery a talipes equinus may result from leaving the foot to drop without support, even when there is no injury to the nerves, muscles or tendons; therefore it is important to maintain the foot at a right angle throughout the treatment of the wound.

7. *Contraction of the Skin and Subcutaneous Tissue from Scarring* may produce talipes of any variety, according to the position of the scars.

The Prevention of Talipes.—The prevention of talipes must evidently depend upon the proper use of methods of splinting during the period of healing of the wound or of union of a fracture. The proper position of the foot is not necessarily exactly the same in every case, the nature of the wound must to some extent be taken into account. But as a general rule, if the foot has been held at right angles to the leg, and with the sole flat, neither inverted nor everted, no fixed deformity will result.

In all injuries above the level of the ankle this position is evidently the correct one, for it overcomes the gastrocnemius and soleus, the most powerful muscles in the leg, and holds the balance between the invertors and evertors. When there is a wound of the ankle itself, the question at once arises as to the probable ultimate result to the joint. If it is probable that there will be ankylosis of the ankle joint, and perhaps of some of the tarsal joints, we must fix the foot in that position which will be most useful for standing and walking. When the patient is standing in an ordinary boot, the foot is in a slight degree of equinus, the heel being raised to an extent

corresponding to the height of the heel of the boot, the sole is flat on the ground, neither inverted nor everted, the heads of the first and fifth metatarsal bones are on the ground. This is the proper position for fixation of the foot when ankylosis of the ankle joint is expected. Fixation in a greater degree of equinus necessitates the wearing of a wedge under the heel, or the performance of an operation. Fixation in calcaneus causes great disability, the patient walking upon the heel only, unless an operation is performed.

If the wound is below the ankle and this joint is not affected, the same position is desirable, particular attention being paid to the

Fig. 122.—Hallux flexus resulting from trench foot. The joint showed marked osteo-arthritic changes.

flatness of the foot, for any inversion or eversion which is allowed is likely to be permanent.

As to the method of fixation of the foot, the surgeon must depend upon certain stock methods, supplemented by his own ingenuity in difficult cases. In fractures and other injuries of the thigh and leg treated upon a Thomas's splint, the foot can be held at a right angle by means of slings glued to the dorsum and sole. When the injury itself does not necessitate the use of a splint, the foot can be held at a right angle upon a club-foot shoe. When the injury is one of the foot itself, the club-foot shoe or the crab splint is the most satisfactory method of fixation in the early stages. When the wound is in a condition to allow of the application of plaster of Paris this is

by far the best method, for not only does it fix the position of the foot securely, but by preventing movement in the tarsal and ankle joints it greatly accelerates the healing of wounds of these joints when they are damaged and infected.

Contractions of the toes may arise during the healing of a wound of the lower limb. It is as necessary to prevent these as it is to prevent the production of a talipes. The most important are flexion of the great toe and clawing of all the toes. Flexion of the great toe may arise in various injuries, from a fracture of the femur to an injury of the sole of the foot. It is only necessary to know of its occurrence in order to prevent it. Clawing of the toes is a more complicated deformity. The toes become hyperextended at the metatarso-phalangeal joints and flexed at the interphalangeal joints. At the same time the transverse arch of the foot is flattened or abolished. If the toes get stiff in this condition the result is very disabling when the patient tries to walk, for the heads of the metatarsal bones are prominent in the sole and are tender, the toes do not meet the ground, and a proper heel-and-toe action in walking is impossible. Here again the chief thing is to know of the occurrence of the deformity. As a rule the sole of the foot should be kept flat upon a plate, such as the sole piece of the club-foot shoe, and the toes should be made to lie down in contact with this. If any tendency to clawing occurs, the toes should be manipulated daily if this is possible.

The Treatment of Talipes.—In the treatment of a talipes which is already established our aims must be—

1. To restore a foot of as nearly as possible normal shape. If, owing to loss of substance or to ankylosis of joints it is impossible to secure a normal looking foot, we should concentrate upon the essentials. We should restore the heel to its normal relationship with the axis of the tibia, see that the weight of the body comes, when the patient is erect, vertically upon the sole, and not upon its inner or outer border, and is supported by the heel and by the heads of the first and fifth metatarsal bones, and make sure that the angle made between the axis of the tibia and the bearing surface of the sole is that which will be suitable for an ordinary boot; that is to say, that the slight degree of equinus already mentioned is within the range of movement if there is some mobility, or is the fixed position if ankylosis has taken place.

2. To restore active mobility in all directions through the normal range. This again may not be possible. It is therefore important to realise which movements are the most essential. These are—

(*a*) Dorsiflexion of 20° over right angle, and plantar flexion of 30° beyond the right angle. Both these should be strong active movements, particularly the latter. If dorsiflexion is not strong it can be assisted or replaced by an instrument with an appropriate spring, if plantar flexion is weak or actively absent it cannot be replaced.

(*b*) Slight inversion and adduction. If this is absent the foot inevitably falls into a position of valgus, causing weakness and discomfort, unless the tarsal joints are ankylosed. If eversion is absent it is possible to support the foot adequately by an appliance, or by tendon fixation.

The treatment of individual cases of talipes may now be considered.

1. *Postural cases* in which there is no fixed deformity, the condition being due to paralysis, division or destruction of muscles. In these the first obvious course is to repair the nerve, muscle or tendon which is injured, if this is possible. A few special cases require mention.

In some cases of injury to the sciatic nerve, repair of the nerve or a part of it is impossible. When the whole sciatic nerve remains paralysed owing to a lesion above the knee, in addition to the completely flail foot there is anæsthesia of the sole and of the outer side of the leg, with a consequent tendency to the formation of trophic sores and to a recurrent swelling of the foot. In these cases, in my opinion, it is better for the patient to have the leg amputated through its middle third, as soon as it is finally established that the nerve cannot possibly recover. For the flail foot is only useful if supported by an apparatus which is as cumbersome and as difficult to keep in order as is an artificial foot, and the removal of the anæsthetic part does away with all the trophic troubles. With an amputation through the middle of the leg the walk is quite as good as it will ever be with a flail foot.

When the internal popliteal element of the sciatic nerve remains paralysed there may be nearly as much disability, and if trophic sores form and remain persistent, again amputation is to be advised. If, however, this complication is absent, a good foot may be made by fixing the tendo Achillis to the back of the tibia, holding the foot in slight equinus.

The tendon should be exposed through a vertical incision in the back of the leg four inches above the heel, split into two halves and separated from the muscle above. The tibia is then bored in two places and each half of the tendon passed through one of the holes, turned back and sutured to itself with just sufficient tension to hold

the foot in the desired position. The foot is fixed in plaster of Paris for six weeks to allow the tendon suture to become firm.

When the external popliteal element is paralysed there are none of the trophic disturbances; the disability is purely mechanical. In this case we may rely upon the permanent use of a foot-drop appliance, such as a double iron and toe-raising spring, or we may fix the tendons of the extensor communis digitorum and of the peronei to the tibia and fibula respectively, by an operation similar to that just described.

When the tendo Achillis has been divided by a wound it is very apt to fail to unite, or to unite with a weak or overlong union, unless special attention has been paid to it. Such a result leaves a great disability, which can only be overcome by shortening or suturing the tendon, an operation which is by no means easy. The tendon should be exposed for a considerable distance up the leg and thoroughly freed on its superficial surface. It will usually be found that the tendon can be identified above and below, and that between there is an indefinite area of fibrous tissue. This should not be completely freed upon its deep surface, as it is desirable to leave some connection to give a blood supply. The tendon above should be split into a superficial and a deep half, the superficial half being free below. This half should then be drawn down and securely sutured to the surface of the intermediate fibrous tissue, or if it is possible to the lower part of the true tendon. The suture should be tight enough to hold the foot in marked equinus. The foot should be fixed in equinus for six weeks.

Division of the tendo Achillis is a sufficiently important injury to render early reparative work advisable, even if sepsis is present. In a recent case I was able to replace the attachment of this tendon under the following circumstances. A wound of the heel had blown off that portion of the os calcis which bore the attachment of the tendon, this piece of bone with the tendon being turned upwards in the leg. The wound was sloughy and infected. The wound was explored, all sloughy tissue and necrotic bone removed, and the area thoroughly treated with BIPP. The separated part of the os calcis was then sutured to its proper place and the foot fixed in equinus. The tendon remained sound, and the separated part of the bone united without further necrosis.

Irreparable damage to the peronei can be treated by fixation of the tendons to the fibula, the foot being held in slight valgus. As a rule after this operation, if the other muscles are intact, the patient can walk well without support.

Cases of Simple Tendon Contraction, with or without surrounding

adhesions in addition, can be treated by correction of the deformity by stretching or by tenotomy. In slight cases daily stretching by hand will often suffice. In more severe cases wrenching under an anæsthetic will correct practically all tendon contractions except those of the tendo Achillis. The latter require tenotomy. The tendo Achillis should practically never be completely divided for this purpose. It should be lengthened by the sliding operation. A tenotome is first introduced on the inner side about half an inch above the attachment to the os calcis, passed half-way across the tendon between it and the skin, and the inner half of the tendon cut through by cutting inwards. The tenotome is then again introduced on the outer side of the tendon about one and a half inches higher up, and the outer half of the tendon divided in the same way. If a little gentle pressure is kept up on the sole of the foot whilst this second cut is being made, and if the cut is made by several strokes, each passing a little deeper, a point is reached when the tendon can be felt to give; a little further pressure upon the sole will now make the two halves of the tendon slide upon each other, and the lengthening can be adjusted to allow just the required amount of dorsiflexion. Six weeks' fixation in plaster of Paris follows (see page 303).

When correction of the deformity has been carried out by wrenching, it is important to correct fully or even to overcorrect. For example, if the foot is in the position of inversion and adduction (Varus), it should be worked at until it is well everted and abducted. If a less degree of correction is attained the result will almost certainly be disappointing, as recurrence of the original deformity is probable. The surgeon's hand, the wedge, and the Thomas's wrench are the methods to be used. The wedge is a simple one of wood, with its apex rounded and about three quarters of an inch wide, padded with indiarubber or by covering it with a folded towel. The foot can be laid over this in any direction and pressure intermittently applied. In using the Thomas's wrench it is not necessary to pad the foot. The wrench may be applied to the bare foot. It must be screwed up tightly, as the skin is more likely to be injured by slipping of the arms of the wrench than by pressure. The best method of exerting force is to use the hip to lever the handle of the wrench, the surgeon's two hands being thus free to manipulate the foot and to feel the strength of the force that is being exerted. In wrenching out a deformity in the foot it is useless to try to hurry. Repeated intermittent pressure exerted for ten minutes will often bring about a correction which seemed impossible in the beginning.

Simple wrenching, with lengthening of the tendo Achillis when necessary, will correct most cases of talipes due to contraction of

tendons and to adhesions. Only those cases in which some of the tendons or muscles are caught in extensive scars in the leg will resist these methods. Of course, such severe wrenching involves much tearing of adhesions, with a liability to a subsequent effusion of blood. Also, if the correction is performed without subsequent fixation of the foot in the overcorrected position, recurrence of the deformity is almost certain to occur. For these two reasons, after the correction of the deformity the foot should be immediately enclosed in plaster of Paris, applied with a uniform pressure whilst the foot is held in the desired position. It is not necessary to apply much padding beneath the plaster, for there should be no undue pressure upon any one point. The plaster should be applied right down to the toes, as otherwise the latter will swell, and it should be applied without any constricting force, but moulded well upon the foot and leg. It is important that the foot should be held in the corrected position whilst the plaster is being applied. If the plaster is applied first and the position of the foot then altered, there will very likely be a constricting pressure upon some point. For example, after lengthening of the tendo Achillis, if the plaster is applied with the foot in equinus, and correction into the dorsiflexed position carried out whilst the plaster is setting, there will almost certainly be a local pressure of the plaster against the front of the ankle, and a sore may develop there. There can be no doubt that the uniform pressure exerted by the plaster of Paris upon the foot and leg prevents the occurrence of much effusion. If for any reason it is thought undesirable to fix a foot or other part which has been severely wrenched in plaster of Paris, it should be enclosed in a thick layer of cotton wool, and a bandage, best of domette or of flanellette, should be applied with a firm uniform pressure from below upwards, and maintained in position for a week. The pressure thus exerted will prevent effusion.

As a rule the corrected position of the foot should be maintained in plaster for a month, or for six weeks if the tendo Achillis has been lengthened. When the plaster is removed it may be necessary to fit a walking appliance, and to use this by day and a club-foot shoe by night to keep up the correction. In this respect each case must be judged separately. Generally speaking, if, when the plaster is removed, the patient is able actively to move the foot in the direction necessary to correct or to overcorrect the original deformity, further support may be dispensed with. If he is not able to do so, it will be better to arrange for an appliance, and to replace the plaster until this is ready. Thus, for example, if the deformity was a talipes equino-varus, which has been corrected by wrenching, with lengthen-

ing of the tendo Achillis, the test to be made when the plaster is removed is for the power actively to dorsiflex and evert the foot. If the patient is able to carry out these movements by use of the extensors and peronei, all further support may be dispensed with, unless it is necessary for some other reason, for example, because the foot tends to fall into valgus, as it sometimes does after lengthening of the tendo Achillis.

When some of the tendons are densely adherent in a scar in the leg, it may or may not be desirable to attempt to free them. If the operation for freeing of tendons were a very satisfactory one, it would be desirable to carry it out in every case. But it is not so. Therefore it is better to reserve this procedure for those cases in which the scar is simple and freeing of the tendons easy, and for those in which operation is essential because the scar prevents the foot coming into the positions which are necessary in standing and walking. For example, if a scar involving the peronei allows the foot to come flat upon the ground, but prevents any but slight inversion, it is only advisable to attempt to free the tendons if the scarring is slight and the peroneal muscles themselves in good condition. If the scarring is severe or the muscles much damaged, setting the tendons free may allow inversion of the foot, but may leave active eversion weak, the result being worse than the original condition. On the other hand, if the anterior tibial muscles are involved in a scar which prevents elevation of the foot, it is more important to set them free, for this movement and its opposite, which will also be limited, are much more important.

Talipes due to scarring of the skin is fortunately not very common. When it is slight in degree, it will usually be possible to restore the essential movements by massage and manipulations. When it is more severe, the only resource is an operation. The scar must be excised and the area covered by a flap. There is seldom any skin to be spared around the ankle, and a pedicle flap taken from the other leg will probably be necessary. When the scars are very severe and it is impossible to correct the deformity except by a severe and perhaps risky operation, it may be better to amputate the foot. This must be judged according to the conditions present in individual cases.

Instances of talipes due to mal-alignment of a fractured bone, or to such conditions as a sub-astragaloid dislocation, must be treated according to general mechanical principles. Thus a mal-united Potts fracture, with bad valgus deformity, will be treated by reconstruction of the fracture and reposition of the bones in such a way as to correct the valgus deformity. Sub-astragaloid dislocation does

not as a rule permit of reposition of the tarsus into its proper relationship to the astragalus and tibia. It is usually necessary to remove the astragalus. Whenever this operation is necessary it should be carried out by Whitman's method.

When the astragalus is removed, the space between the malleoli of the tibia and fibula is insufficiently wide to rest upon the os calcis accurately. Consequently the foot tends to turn on to its outer side, a talipes varus resulting. In Whitman's operation the astragalus is approached from the outer side by an incision along the line of the peroneal tendons. The latter are drawn out of the way, or divided if necessary. The ankle joint is then opened and the foot dislocated inwards by force. The astragalus can then be easily removed. Pockets are then prepared for the malleoli on the inner and outer sides. That for the inner malleolus is made by cutting into the tissues on the inner side of the sustentaculum tali, inferior calcaneo-scaphoid ligament and scaphoid. That for the outer malleolus is made by removing a small slice of the outer side of the os calcis and cuboid at the level of the calcaneo-cuboid joint. When these pockets are deep enough to receive the malleoli, and to allow the tibia to come down into contact with the tarsus, the peroneal tendons are sutured, if they have been divided, and the wound closed. The foot is thus displaced backwards upon the tibia and fibula, which now rest upon the calcaneo-cuboid joint. It is fixed in plaster of Paris for six weeks. This operation results in a good foot, without tendency to fall into varus or valgus, and with a small but useful range of movement.

When the tarsal bones or ankle joint have been badly damaged, so that the talipes is due to ankylosis or to destruction of bone, it must always be a question whether the foot should be kept or should be amputated. The points for and against amputation have been already considered. As a rule, when the foot has been retained until the wounds are soundly healed, an attempt should be made to render it serviceable.

By the removal of wedges of bone, with wrenching and tendon lengthening, we should try to secure a foot that is set at the correct angle to the leg, and the bearing points of which come in proper contact with the ground in walking. If this is impossible, or if it involves an operation which may endanger the nutrition of a part of the foot, it will even then be better to amputate, rather than to submit the patient to an operation, the benefit of which may be problematical, when we know that an amputation will probably lead to a better functional result.

Functional Talipes.—It must be remembered that some cases of

deformity of the foot are purely functional in origin, and that in these treatment must be on quite different lines from that which is adopted in cases of organic origin. After injuries to the leg or thigh the most frequent functional deformities of the foot are (1) spasmodic talipes equino varus, or functional inversion of the foot, and (2) postural talipes equinus, or functional foot-drop. The former of these comes into the group of functional deformities associated with spasm, the latter into the group of flaccid functional paralyses. In either case care must first be taken to exclude any organic lesion, such as an irritative lesion of the internal popliteal nerve in the first group, or a paralysis of the extensors or contraction of the tendo Achillis in the second. In all cases the treatment should be purely by persuasion and re-education, after a preliminary examination under an anæsthetic, if this is necessary, to prove that mobility is really free. Local treatment, whether by correction and fixation in plaster or on a splint, or by tenotomy, or by massage and electrical treatment, is to be deprecated. It is very likely to make the condition worse by drawing the patient's attention to his deformity.

In certain other cases of apparent talipes it will be found that there is some defect in the foot, usually in the toes, which renders it painful for the patient to place his foot flat upon the ground. For example, there may be a rigidity of the great toe in the flexed position, and any attempt to extend the toe may be painful (hallux rigidus). The patient in order to avoid pressure upon this toe walks upon the outer side of the foot, producing an apparent talipes varus. In another case there may be a painful corn upon the little toe, producing eversion of the foot (talipes valgus). In such cases the proper treatment is that which aims at curing the local painful condition. The talipes will then disappear, either spontaneously or as the result of a few simple re-educational exercises.

Deformities of the Toes.

It would be out of place, in discussing the after treatment of injuries, to enter into all the deformities of the feet and toes; but certain contractions of the toes are specially frequent as a result of injuries of the lower limb and of frostbite, and are therefore met with in military surgery; their treatment is naturally conducted upon the same principles as are adopted in treating the same conditions when they occur in civil practice, even though the cause is different.

Clawing of the toes in association with pes cavus has been already mentioned; it is a common result of trench foot, and may be very severe and very disabling. The longitudinal arch of the foot is

exaggerated, the transverse arch is lost, so that the heads of all the metatarsal bones rest upon the ground, the toes are hyperextended at the metatarso-phalangeal joints, and flexed at the interphalangeal joints. The disability depends first upon the fact that the whole of the metatarsal heads rest upon the ground heavily, and that they consequently become painful, in the second place the toes may not reach the ground at all, but may remain clawed up in the air, the whole fore part of the foot is stiff, and the patient walks upon the foot without any spring, using it as a stump. In some cases the sole will not come beyond the position in which it is at a right angle to the leg, and in bad cases the patient may walk upon the toes without the heel meeting the ground at all.

The correction of such a deformed foot into a natural shape is possible, but very difficult. To maintain such a correction is almost impossible. Probably the immediate cause of the deformity is a paresis of the intrinsic muscles, and this cause persists and brings about a recurrence of the deformity. It is as well, therefore, to concentrate the attention upon treating the disabling elements of the condition without attempting an anatomical cure. The essentials are—

1. To enable dorsiflexion of the foot to pass the right angle. This should be done by division of the plantar fascia and wrenching, with fixation of the foot in the corrected position for four to six weeks. It is a mistake to divide the tendo Achillis.

2. To free the toes so that they can be actively flexed by the patient sufficiently to enable them to meet the ground. In slight cases this can be done by simple manipulation under an anæsthetic, followed by massage and manipulation in a hot bath. In more severe cases it may be necessary to divide the extensor tendons of the second to fifth toes, at the same time as the plantar fascia is divided; the toes are then held in a well flexed position in the plaster.

3. To produce a transverse arch. When the plaster is applied the fore part of the foot should be cramped sideways and firmly bandaged with the plaster immediately behind the heads of the metatarsal bones. When the plaster is removed the transverse arch must be supported, either by strapping applied around the same part of the foot, or by a foot-plate made upon a plaster cast of the foot taken with this arch reconstructed.

4. Subsequent treatment by massage, exercises to restore active control of the movements (particularly flexion) of the toes, and walking exercises to induce a proper heel-and-toe action in place of the faulty, stump-like action, usual in these patients.

The great toe may be clawed in these cases, but it usually comes flat upon the ground when dorsiflexion of the foot has been secured. It is a mistake to divide the extensor tendon of this toe when the others are divided, for the tendon may fail to unite and a permanently flexed toe may result. If it is essential to lengthen this tendon this should be done by an open operation, the tendon being split and the two halves sutured together after sliding. A common deformity in the great toe is a fixed flexion. This condition of hallux flexus is frequent in civil practice as the result of an osteoarthritic condition (Hallux rigidus); it occurs in military surgery also as a sequel to trench foot and in cases of injury higher up the limb, when the position of the toes has been neglected. If there is little or no thickening of the joint it may be possible to extend the toe by force and to hold it in a hyperextended position. More often there is much thickening of the joint, and other indications of an osteoarthritic condition in the joint. It will then be necessary to excise the head of the metatarsal bone, performing an arthroplasty upon the joint.

This operation should be conducted upon exactly the same lines as that usually performed for hallux valgus, and known as Mayo's operation. A curved incision is made over the dorsum of the joint with the concavity inwards. The flap of skin is reflected inwards as far as the inner side of the joint; if a bursa is present it is best opened, the superficial half of the bursa being reflected in the flap, the deep half being left for subsequent use. If the skin is reflected without any of the bursa, the flap may be so thin as to endanger its nutrition. A flap, consisting of the deep half of the bursa and of areolar tissue, is then cut, with its pedicle over the neck of the metatarsal bone, its width being about an inch. This is reflected backwards. The joint is then opened on the outer side, the capsule of the joint being left attached to the first phalanx, and the head of the metatarsal bone is cleared back to the neck. With a large pair of bone forceps the metatarsal bone is divided through its neck and the head is removed, the stump should be inspected for any spike remaining, and levelled off. The bursal or fibrous flap is then turned in over the cut surface of the neck of the bone, and the capsule of the joint attached to the tissue over the neck of the metatarsal by one or two sutures. The skin is then closed. As soon as the wound is healed the patient should start walking, and movements of the new joint should be encouraged. If there is any tendency for the great toe to remain raised from the ground, strapping applied around the transverse arch will bring it down.

Various partial operations have been devised for this condition,

the object being to save the head of the metatarsal bone, which is one of the chief bearing points of the foot. It may be said that these are all failures. As a rule, the condition is due to or kept up by osteoarthritic changes in the joint, and nothing short of an excision of this joint will remedy it. Two to three months after the above described operation the foot is practically normal.

CHAPTER XV

INJURIES OF THE NERVES OF THE LOWER LIMB

The nerves of the lower limb are derived from the twelfth dorsal, all the lumbar and the first four sacral roots through the lumbar and sacral plexuses. These plexuses are situated in well-protected regions, where they are only liable to injury by wounds which penetrate deeply and which are likely at the same time to injure vital structures. Therefore injuries to the plexuses are rare. With the exception of the great sciatic nerve, the nerves to the lower limb have already divided into comparatively small branches before they enter the limb, for this reason injuries to the nerves of this limb, apart from injuries to the sciatic nerve, are less common and less important than are those of the nerves of the upper limb.

The Lumbar Plexus.

The lumbar plexus is formed by the upper four lumbar roots, with a small slip from the last dorsal nerve. From the fourth lumbar nerve a considerable branch passes downwards to join the fifth lumbar, and form the lumbo-sacral cord which enters into the sacral plexus.

The first four lumbar nerves are arranged in a comparatively simple way, as shown in Fig. 123. The branches are formed in the substance of the psoas muscle, and escape from it through its anterior surface, internal or external borders.

The ilio-inguinal and ilio-hypogastric nerves, derived chiefly from the first lumbar nerve, supply the skin over the outer side of the hip and the groin, and a few twigs to the internal oblique and transversalis muscles. They are of practically no surgical importance.

The genito-crural nerve is derived chiefly from the second lumbar nerve. It escapes from the psoas through its anterior surface, and runs down upon this muscle as far as Poupart's ligament. Here it divides into a genital branch, which is distributed to the skin of the scrotum, and a crural branch, which supplies a small area of skin over Scarpa's triangle. In some cases of injury to this nerve there is an area of hyperaesthesia over the upper part of the thigh and

over the scrotum. Apart from the occasional occurrence of these symptoms the nerve is of no surgical importance.

The external cutaneous nerve is derived from the second and third lumbar nerves, escapes from the psoas through its outer border, and crossing the iliacus, passes beneath Poupart's ligament immediately internal to the anterior superior spine of the ilium. In the thigh it supplies the skin over the outer side as far as the knee. Injury in the upper part of the thigh causes a considerable area of anæsthesia, if incomplete a hyperæsthetic area may result, or there may be a severe neuralgia, necessitating exsection of a portion of the nerve. When this is necessary the nerve should be looked for beneath the deep fascia immediately below the anterior superior spine.

The anterior crural nerve is derived from the second, third and fourth lumbar nerves, it escapes from the psoas through its outer border and passes down to Poupart's ligament in the groove between the psoas and iliacus muscles, entering the thigh in this situation just external to the femoral artery. As it enters the thigh it divides into a number of branches, which are usually divided into a superficial and a deep set. The superficial set of branches include the middle and internal cutaneous nerves and the nerves to the sartorius and pectineus, the deep set supply the quadriceps extensor cruris, and include the long saphenous nerve.

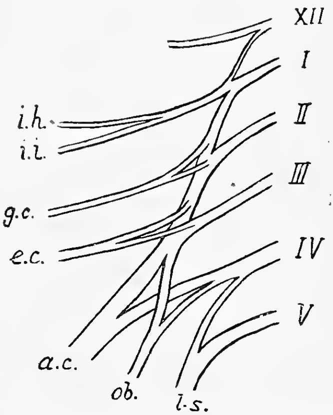

FIG. 123.—Diagram of the Lumbar Plexus: *i.h.* ilio-hypogastric nerve, *i.i.* ilio-inguinal nerve, *g.c.* genito-crural nerve, *e.c.* external cutaneous nerve, *a.c.* anterior crural nerve, *ob.* obturator nerve, *l.s.* lumbo-sacral cord.

The middle cutaneous nerve consists of two parts, one of which usually pierces the sartorius; these supply the skin over the front of the thigh as far as the knee.

The internal cutaneous nerve passes down the inner side of the thigh, supplying the skin as far as the middle of the calf.

The sartorius is supplied by a branch which arises with the middle cutaneous nerve, the pectineus by a branch which arises high up with the internal cutaneous nerve, and which passes behind the femoral vessels.

The nerve to the rectus femoris enters the deep surface of the muscle, running downwards for some distance under cover of the muscle.

The nerve to the vastus externus descends along the anterior border

of the muscle in company with a branch of the external circumflex artery.

The nerve to the crureus consists of several filaments, which enter the superficial surface of the muscle.

The nerve to the vastus internus runs down with the long saphenous nerve beneath the fascia which covers the femoral vessels. It gives a series of twigs to the muscle, which it finally enters. In case of doubt it can be distinguished from the long saphenous by the presence of these muscular branches, for the long saphenous gives off no branches in this situation.

The internal or long saphenous nerve accompanies the femoral vessels throughout Hunter's canal, leaving them only when they pass through the opening in the adductor magnus. Below this it continues down the inner side of the leg in association with the internal saphenous vein, passing in front of the internal malleolus and ending on the inner side of the foot. It supplies the skin over the inner side of the knee, leg and foot as far as the base of the first metatarsal bone, or even as far as the ball of the great toe.

Motor Symptoms of Paralysis of the Anterior Crural Nerve.—The situation of the anterior crural nerve explains the rarity of injuries. When a wound involves this nerve it is very likely at the same time to injure the femoral vessels. The typical paralysis is that of the quadriceps extensor cruris muscle. Voluntary extension of the knee is impossible, but the patient is able to walk comparatively well along a level surface, as soon as he has learnt the method. Without any action on the part of the quadriceps the knee is quite stable, provided that it is hyperextended. If the knee flexes whilst the weight is upon it, it gives way. The patient is unable to walk upstairs or up a hill, because in these actions active extension of the knee is essential.

Injury to the individual muscular branches of the nerve would seem to be almost as rare as injury to the nerve itself, probably because these branches have for the most part a comparatively short course before they enter the muscles that they supply. In the severe injuries in which there is a compound fracture of the femur, the branches of the anterior crural nerve must be frequently injured, but the resulting stiffness of the knee obscures the consequent weakening of the quadriceps.

Anæsthesia.—Complete lesions of the anterior crural nerve cause anæsthesia over the front of the thigh, inner side of the knee, and inner side of the leg and ankle.

Injury to the long saphenous may cause an anæsthesia, localised to the inner side of the leg and ankle. Irritation of this nerve may

cause a neuralgia over the same area. The sensory branches of the anterior crural, and specially the long saphenous, must be remembered as possible causes of a painful area in an amputation stump through the thigh or leg.

Operation.—In rare cases of injury to the anterior crural nerve at the level of Poupart's ligament, the nerve has been successfully sutured. No special splinting is required.

The obturator nerve is derived from the second, third and fourth lumbar nerves. It escapes from the psoas through its inner border, and passing across the side of the pelvic cavity above the obturator vessels emerges from the pelvis through the upper part of the obturator foramen. In the foramen it divides into anterior and posterior branches. The anterior branch supplies the gracilis, adductor longus and adductor brevis, the posterior supplies the adductor brevis and adductor magnus, and the obturator externus.

Injuries to the obturator nerve are rare. A case in which a foreign body, lodged in the region of the obturator foramen, kept up external rotation of the hip has been mentioned in the last chapter. This was possibly due to irritation of the obturator nerve, possibly to irritation of the obturator muscles themselves.

The Sacral Plexus.

The sacral plexus is formed by the lumbo-sacral cord and the first three sacral nerves, with a small slip from the fourth sacral nerve. These unite into a large upper trunk, the great sciatic, and a small lower trunk, the pudic, several small nerves arising separately from the interlacing mass of the plexus. These are shown diagrammatically in Fig. 124.

The usual origin of the nerves from the lumbar and sacral roots is set out in the following table.

	L IV.	L V.	S I.	S II.	S III.	S IV.
Superior gluteal . . .	+	+	+			
Inferior gluteal . . .		+	+	+		
External popliteal . .	+	+	+	+		
Internal popliteal . . .	+	+	+	+	+	
Small sciatic			+	+	+	
Quadratus femoris . .	+	+	+			
Pyriformis			+	+		
Obturator internus . .		+	+	+		
Pudic			+	+	+	+

The pudic nerve and the muscular branches to the quadratus femoris, obturator internus and pyriformis are of little surgical importance and need not be further mentioned.

The superior gluteal nerve is derived from the fourth and fifth lumbar and first sacral nerves. It leaves the pelvis through the great sacro-sciatic foramen above the pyriformis, and divides into two branches which run outwards between the gluteus medius and minimus, supplying these muscles and the tensor fasciæ femoris. It is seldom injured except in severe wounds which have destroyed much of the buttock.

The inferior gluteal nerve is derived from the fifth lumbar and first and second sacral roots. It escapes from the pelvis through the great sacro-sciatic foramen, passes below the pyriformis and at once breaks up into branches, which are distributed to the gluteus maximus muscle, entering its deep surface. The nerve as a whole is seldom divided. individual branches are likely to be injured in wounds of the buttock, usually with accompanying destruction of the gluteus muscle. An isolated paralysis of the gluteus maximus muscle is very rare.

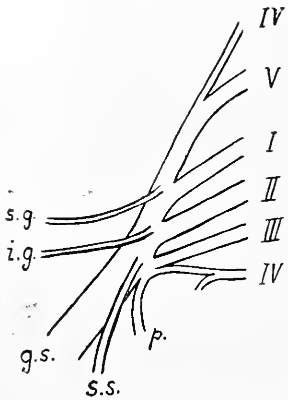

FIG. 124.—Diagram of the Sacral Plexus: *s.g.* superior gluteal nerve, *i.g.* inferior gluteal nerve, *g.s.* great sciatic nerve, *s.s.* small sciatic nerve, *p.* pudic nerve.

The small sciatic nerve is derived from the first three sacral roots. It leaves the pelvis in company with the great sciatic nerve lying upon its posterior surface. It supplies the skin over the back of the thigh and upper half of the calf. It is of little surgical importance except in painful lesions.

The Great Sciatic Nerve.

Anatomy.—The great sciatic nerve emerges from the pelvis under cover of the pyriformis muscle. At the lower border of this muscle it lies upon the obturator internus and gemelli, and then upon the quadratus femoris, under cover of the gluteus maximus, resting in the hollow between the tuberosity of the ischium and the great trochanter. In the back of the thigh it rests upon the adductor magnus, being crossed by the long head of the biceps, which then lies upon its outer side, the semi-membranosus and semi-tendinosus being on the inner side. Towards the lower third of the thigh it divides into its internal and external popliteal branches.

The division into these main branches occurs at a variable level. In some cases the division is much higher up in the thigh, in some the two nerves may be separate right up to the sciatic notch. In this case the nerves to the hamstring muscles arise from the internal

popliteal division, except that to the short head of the biceps, which is associated with the external popliteal.

The only branches given off by the great sciatic nerve before its division are those to the hamstring muscles. These may arise separately or may come off in one nerve, which will then arise high up under cover of the gluteus maximus. The branch to the semi-tendinosus always arises high up, those to the long head of the biceps and to the semi-membranosus arise somewhere in the upper half of the thigh.

The internal popliteal nerve continues in the line of the sciatic trunk down the middle of the popliteal space, lying at first external to, then behind, the artery. At the lower border of the popliteus muscle it becomes the posterior tibial nerve. The latter runs down the back of the leg beneath the gastrocnemius and soleus muscles, lying upon the deep muscles. It is at first internal to the artery, crossing behind that vessel in the middle of the leg. At the back of the internal malleolus the nerve curves forwards into the sole, lying behind the vessels, between them and the tendon of the flexor longus hallucis. Here it divides into the internal and external plantar nerves.

In the popliteal space the internal popliteal nerve gives off first a cutaneous branch, the nervus communicans tibialis, which joins with a similar branch from the external popliteal to form the external saphenous nerve. This perforates the deep fascia about the middle of the back of the leg, and supplies the skin over the outer surface of the lower part of the leg, the outer surface of the heel and the external border of the foot.

In the popliteal space branches are also given off to the gastro-cnemius and soleus and to the popliteus, also articular branches to the knee joint.

The posterior tibial nerve gives off branches to the tibialis posticus, flexor longus digitorum, and flexor longus hallucis. These all arise in the upper half of the leg. Close to the ankle it gives off a sensory branch to the skin over the inner side of the heel.

The internal plantar nerve supplies muscular branches to the abducter hallucis and flexor brevis digitorum, and digital sensory branches to the inner side of the great toe and to the intervals between the first and second, second and third, and third and fourth toes.

The external plantar nerve supplies the rest of the intrinsic muscles of the sole, and digital branches to the outer side of the little toe, and to the adjacent sides of the fourth and fifth toes.

The external popliteal nerve inclines outwards from the internal popliteal, running along the outer side of the popliteal space, immedi-

ately internal to the biceps tendon. Below this it lies in the groove between the biceps tendon and the outer head of the gastrocnemius as far as the neck of the fibula, where it inclines forwards round this bone under cover of some fibres of the peroneus longus muscle and a fibrous arch from which these spring. In this situation it divides into two branches, the anterior tibial and the musculo-cutaneous.

The anterior tibial nerve inclines forward under cover of the peroneus longus and extensor communis digitorum until it comes to lie upon the interosseous membrane and meets the anterior tibial artery. It continues down the front of the leg, lying upon the interosseous membrane between the tibialis anticus on the inner side and the extensor longus digitorum and extensor longus hallucis on the outer side. The artery is internal to, and some distance from, the nerve in the upper fourth of the leg, behind the nerve in the middle two fourths, and internal to the nerve in the lower fourth. At the level of the ankle joint the nerve passes beneath the anterior annular ligament and is crossed by the tendon of the extensor longus hallucis. Immediately below the anterior annular ligament it divides into internal and external branches. The internal branch continues forwards to the first interspace, sometimes supplying a small area of skin over the inner part of the dorsum of the foot, the external branch lies beneath the extensor brevis digitorum and supplies this muscle, ending in an enlargement over the tarsus, similar to that upon the posterior interosseous of the forearm.

The musculo-cutaneous nerve continues downwards from its origin in the substance of the peroneus longus muscle, and then in the interval between this muscle and the extensor communis digitorum, reaching the surface through this interval in the lower third of the leg. It divides into two branches in the leg, and these pass in front of the anterior annular ligament; the inner branch supplies digital branches to the inner side of the great toe and adjacent sides of the first and second, and second and third toes. The outer branch supplies digital twigs to the adjacent sides of the third and fourth, and sometimes to the fourth and fifth toes. The supply of the skin on the dorsal aspect of the toes is variably distributed between the anterior tibial, musculo-cutaneous, and short saphenous nerves. The anterior tibial often supplies a branch to the adjacent sides of the first and second toes, and the short saphenous usually supplies the interval between the fourth and fifth toes as well as the outer side of the little toe.

The external popliteal nerve gives off only two branches in the popliteal space. One, the nervus communicans fibularis, runs downwards over the outer head of the gastrocnemius, joining the

nervus communicans tibialis about the middle of the calf. The other, the lateral cutaneous nerve of the leg, arises at the same level and supplies the skin over the outer side of the antero-external surface of the leg.

The anterior tibial nerve supplies branches to the tibialis anticus and extensor communis digitorum muscles, as it lies between these muscles in the upper third of the leg. Lower down, about the middle of the leg, it supplies the extensor longus hallucis.

The musculo-cutaneous nerve supplies branches to the peroneus longus and peroneus brevis. The former muscle receives branches in the upper third of the leg as the musculo-cutaneous nerve passes through its substance. The peroneus brevis receives its supply about the junction of the upper and middle third of the leg.

Motor Symptoms.—The symptoms of paralysis of the sciatic nerve will vary according to the level at which the injury takes place. For example, in a complete lesion at the sciatic notch there will be a paralysis of all the muscles of the limb except those of the buttock, the quadriceps extensor cruris and the adductors. If the injury is at a lower level, the hamstring muscles, or some of them, may escape. But in so large a nerve as the sciatic, injury to a part of the nerve is not uncommon, so that we may see, even in a lesion high up in the thigh, symptoms of division of the internal popliteal nerve, the external popliteal having escaped. Or we may find symptoms of division of one half of the nerve and irritation of the other half, or we may find a still more localised injury, so that only certain individual muscles are paralysed.

For this reason, in all cases of injury to the sciatic nerve a very careful examination of the voluntary power and electrical reactions of all the muscles of the limb should be made. For it may be found that some muscles have escaped, and when the nerve is exposed it may be possible to separate the nerve fibres, which are continuous, leaving them intact and only suturing the rest of the nerve.

In paralysis of the various groups of muscles of the lower limb the examination for the loss of voluntary power is easy, for the individual muscles have in practically every case a simple action, and their tendons can be felt or seen. The only muscles in which contractions cannot be felt are such comparatively unimportant ones as the popliteus.

Paralysis of the sciatic nerve must be sought for systematically, or it may be missed, at least in the early stages. The patient lies in bed with his knee extended and foot dropped. When the hip is flexed, the knee flexes also as the result of the action of gravity, even though the flexors are paralysed. The dropped foot may be taken to

be simply a natural position for a patient who is recumbent. Omission of the diagnosis is even more likely in the case of a paralysis of the internal popliteal nerve. For the foot drops, again as the result of the action of gravity, and the fact that the patient is unable actively to plantar flex the foot may be missed. Paralysis of the external popliteal nerve is less likely to be missed, because the absence of voluntary power of dorsiflexion is more evident.

In cases in which a lesion of the sciatic complicates a fracture of the femur, it is still more likely to be overlooked. In every case of fractured femur an early systematic examination of the voluntary power in the leg muscles should be made, and any loss of sensation in the leg and foot noted. The presence of a sciatic paralysis is an important complication in a fractured femur. It greatly affects the prognosis, and its presence must often be a determining factor when amputation is being discussed. It also affects the method of treatment, for there can be no doubt that the presence of a sciatic injury is often the cause of the sores that develop as the result of friction or pressure by the extension or by the splint.

In all cases of injury to the sciatic or to its branches an electrical examination of the muscles of the limb should be carried out. Partial lesions of the nerve or of its branches are common, due to a projectile having divided one half of the nerve or having pierced the nerve. In such cases an accurate diagnosis can only be made by finding that certain of the muscles show a changed electrical reaction (disappearance of faradic response, and slowing of the galvanic response), whilst others show a normal reaction. In cases examined soon after the injury the muscles may all appear to be paralysed, but may show a normal electrical response. This may be due to the fact that sufficient time has not elapsed to allow the reaction to alter, or it may be due to the fact that the nerve is not really divided, the paralysis being due to concussion. Further observation and the repetition of the electrical test will clear up the diagnosis. Perhaps the reactions will alter in all the muscles, showing that the nerve is divided; perhaps it will alter in some muscles only, remaining normal in others, showing that there is a partial lesion; or perhaps the reactions will remain normal, showing that there is no interruption of the nerve. In the latter case a return of voluntary power may be confidently expected.

Anæsthesia.—As is the case in the upper limb, the area of anæsthesia resulting from a complete lesion of the sciatic nerve is much less than might be expected if only the strict anatomical distribution of the nerves is considered. The maximum area affected comprises the whole of the sole and heel of the foot, the dorsal surface of the fore

part of the foot, the outer side of the ankle, and the outer surface of the leg as high as the knee. The anæsthesia of the sole is constant, the anæsthetic area on the dorsum of the foot and on the leg varies. It may be confined to a much smaller area.

In lesions of the branches, the anæsthetic area depends upon the nerves affected and upon the level at which they are paralysed. Thus division of the whole internal popliteal element above the popliteal space will cause anæsthesia of the whole of the sole and of the heel, and probably also of the outer side of the foot and of the dorsum of the fourth and fifth toes, and of the terminal phalanges of the other toes. If the injury is below the origin of the communicans tibialis the outer side of the heel and the outer border of the foot will escape. Division of the whole of the external popliteal element often causes a comparatively small area of anæsthesia, limited to a part of the dorsum of the foot and a small area over the antero-external surface of the ankle and leg. If the lesion is below the origin of the communicans fibularis and lateral cutaneous branches there is only a small anæsthetic area on the dorsum of the foot. As these nerves arise high up in the popliteal space, they often escape in injuries to the external popliteal trunk.

Irritative and painful lesions are rare in the external popliteal element, comparatively common in the internal popliteal. In this respect the former corresponds with the musculo-spiral nerve in the arm, with which it is homologous, the latter with its homologues, the median and ulnar. In irritative lesions of the internal popliteal nerve there may be a considerable spasm of the calf muscles, including the tibialis posticus, causing a plantar flexion and inversion of the foot (talipes equino-varus). When this condition is associated with a disappearance of voluntary power in the opposing muscles there may be a real difficulty in diagnosis. Both the deformity of the foot and the paralysis may be due to a functional condition; on the other hand, either or both may be due to a real injury. In other words, there may be an irritative lesion of the internal popliteal, with interruption of the external, or there may be an irritative lesion of the internal popliteal with functional paralysis of the opposing muscles, or the whole condition may be functional. The diagnosis must depend upon—

1. A careful examination of the site of the wound, considering the possibility of injury to the nerves, and the presence of a painful spot upon one or other of them.

2. An investigation of the area of anæsthesia, if any, with a consideration whether it accords with the distribution of a nerve or whether it is of functional type.

3. The electrical changes in the muscles, which should finally settle the nature of the paralysis, although they will not be so definite in settling the cause of the spasm.

Trophic Changes.—These are comparatively uncommon, except in the rare cases of painful lesions of the internal popliteal element, which come within the class of causalgias. But although trophic changes in the skin, nails, muscles, etc., do not occur in simple division, the loss of sensation and of innervation renders the foot peculiarly liable to the formation of chilblains, and of sores from friction and pressure, and these heal with great difficulty. These sores, often classed as trophic, are important, for they constitute one of the reasons which may render amputation advisable in lesions of the sciatic nerve in which suture of the nerve is impossible.

Operation.—Throughout the greater part of its course the sciatic nerve and its branches can be readily explored through an incision along the course of the nerve. Where the nerve lies under cover of the gluteus maximus the mode of procedure must depend upon the nature of the injury. In any case a curved incision should be made along the line of the nerve, the skin being reflected a short distance and the gluteus maximus exposed as low as its lower border. If the wound is a simple one and a localised lesion expected, the nerve may be exposed by splitting the muscle in the direction of its fibres. If the exposure thus given is insufficient, the lower fibres of the muscle should be divided close to their insertion into the trochanter and fascia lata, and reflected inwards; the whole nerve can thus be exposed from the sciatic notch down into the back of the thigh. It is unnecessary to divide the muscle transversely in the line of the nerve.

The posterior tibial nerve in the middle of the leg may not be easy to find. It should be exposed by an incision just behind the inner border of the tibia, which divides the soleus muscle. A strong layer of fascia will be found beneath this muscle, in which is a fascial compartment which contains the nerve and vessels. The common mistake is to divide the fibres of the flexor longus digitorum with those of the soleus, and to look for the nerve beneath this muscle instead of upon its posterior aspect.

In all operations upon the sciatic nerve means should be at hand for testing the electrical conductivity of the nerve at the time of operation. The discovery of partial lesions will be frequent, and very often it is possible to split off the sound part of the nerve, which can be proved to supply certain of the muscles, leaving it intact, and excecting the ends of the remainder of the nerve and suturing it. This applies equally to injuries of the internal and external popliteal divisions of the nerve.

Flexion of the knee gives a very considerable additional length in the sciatic nerve and in its branches, and the operation of exploration should never be undertaken until the knee can be flexed to a right angle. This warning is particularly applicable to cases of injury of the sciatic nerve which complicate a fracture of the femur. In these cases after the fracture is united the knee should be flexed by some gradual method, such as the use of a MacIntyre splint, and only when flexion reaches the right angle should the nerve be explored.

After the operation, if there is the least tension upon the nerve, the knee should be kept flexed for six weeks.

Splinting and Appliances.—After suture of the sciatic nerve or of its branches, or during recovery from paralysis, certain of the muscles, if paralysed, will require support. The hamstrings recover quite well without any application of a splint. The posterior tibial group require a certain amount of support. For the anterior tibial group support is essential. As in other paralyses, the support is required for two purposes, first, to prevent the production of a fixed deformity by the permanent contraction of the opposing muscles, and second, to prevent overstretching of the paralysed muscles. Paralysis of the posterior tibial muscles causes a calcaneus deformity; in addition, the withdrawal of the support given by the gastrocnemius to the back of the knee may cause hyperextension of this joint. The foot deformity can be best prevented, whilst the patient is in bed, by the use of a right-angled club-foot shoe; after he gets up, by raising the heel half an inch and fitting a metal tongue in the boot. The latter forms an anterior splint to the ankle and prevents dorsiflexion of the foot. If there is any tendency to hyperextension of the knee, side steels should be fitted to the thigh and leg and carried to the boot. A strap should then be attached to the thigh band and fastened to the back of the heel of the boot, with sufficient tension to keep the knee slightly flexed and the foot plantar flexed.

In cases of external popliteal paralysis a club-foot shoe should be worn rigidly from the first, and when the patient gets up he should wear a boot with a double iron, varus T-strap, and toe-raising spring, or else a more elaborate steel-and-leather appliance to serve the same purpose. The club-foot shoe should still be worn whenever the boot is removed, the patient never being without one or the other. In these cases there is a real tendency to the formation of a fixed talipes.

The operations for tendon fixation for irrecoverable paralysis of the popliteal nerves have been already described.

Amputation in Sciatic Paralysis.—Whilst amputation should never be lightly advised or undertaken for a paralysis of the sciatic nerve,

there can be no doubt that the presence of such a paralysis must often be an important factor in determining the sacrifice of a limb. In cases of complete paralysis of the nerve, when the foot is flail and trophic sores are present, the first procedure should be the exploration and suture of the nerve. If satisfactory suture is impossible, or if a year after suture no recovery has taken place, it may be better to amputate the limb, for the flail foot will never be as functionally useful as an artificial foot, and the trophic sores will constitute a great disability, for which a complete cure is impossible as long as the paralysis is present. The trophic condition must here be the determining factor. In such cases an amputation through the middle of the leg is that which should be carried out, and preferably the flap should be taken from an area of skin which possesses sensation.

In certain cases of fracture of the femur, the presence of a complete lesion of the sciatic nerve may determine the surgeon to amputate the limb. Practically the only cases in which this decision will be arrived at are those of bad compound fractures low down in the femur, in which there is much comminution and sepsis, in which union is delayed, and in which the eventual result will be a short leg and a stiff knee, with a paralysed sciatic nerve, which cannot be sutured until a year or more after the injury. In such cases we may come to the conclusion that it is justifiable to cut short the treatment by amputating, provided that a fairly long femoral stump can be left. For by so doing we may be able to save a year's treatment and to leave a functional result which is at least as good as would be got by more conservative methods.

CHAPTER XVI

INJURIES OF THE SPINE

Injuries of the back and spine constitute a group in which mechanical treatment by posture and support is very important, and is apt to be neglected, largely because of its supposed difficulty. In extensive injuries to the skin and muscles of the back as well as in fractures of the spine, an after deformity in the shape of a posterior or lateral curvature of the spine is common, and often considered to be inevitable. Treated upon sound mechanical lines these conditions ought to leave little or no deformity.

Extensive Wounds of the Back.

Wounds of the back, if they have failed to penetrate the thorax or abdomen or to injure the spinal cord, may cause extensive destruction of the skin and muscles without seriously endangering life. Large areas of skin may be lost, or more commonly the skin may be divided along a transverse or oblique line, and by retracting greatly may leave a large granulating area exposed. The latissimus dorsi, scapular muscles and erector spinæ may be divided, leaving, if they have not been sutured, an eventual difficulty in the maintenance of the erect position. Owing to pain and to difficulties in nursing there is a tendency to allow patients who suffer from such wounds to sit in bed with the spine in a flexed position, or to lie curled up on the side. The effect of this is to allow the wound to granulate up with the skin edges widely separated, and the cut surfaces of the muscles kept apart by an interval, so that their action must in the end be interfered with much more than would be the case if the separated parts could be held in contact.

In these cases the maintenance of the extended position of the spine from the first is most important. For if this position can be secured the separation of the cut edges of the skin and of the muscles is reduced to a minimum. In order to secure union of the divided muscles it is also important that in such wounds early secondary suture should be adopted in as many cases as possible. Or if this has been impossible, a later excision of the scar and granulating area should be carried out, the muscles being brought together and sutured

as securely as possible. These are not wounds that can be left to heal slowly, as the result of a masterly inactivity. This method no doubt secures healing with the least trouble to the patient and surgeon, but it will often leave an unnecessary disability, for which further surgical treatment may be required.

Excision and suture of wounds of the back is a comparatively easy procedure, for the laxity of the skin over the back and lumbar regions enables even very large areas to be closed in by undercutting the skin. The careful excision of all damaged and scarred tissue, and of all granulations, with the use of BIPP, will enable such an excision to be performed and the wound sutured with only a small drain, with comparatively little risk of failure of primary healing.

The suture of muscles such as the latissimus dorsi and erector spinæ when they have been divided in a direction at right angles to that of their fibres is not easy. It can be facilitated by leaving a little scar tissue in the cut edges of the muscle; this will prevent the sutures from cutting out as soon as tension is placed upon them. As a rule no attempt should be made to pass sutures direct through each half of the muscles and simply to pull them together; such sutures will almost certainly cut out if there is any tension. Instead, sutures of strong catgut should be passed transversely through some of the fibres above the injury, weaving them in and out among the fibres. They should then be passed in the opposite direction through the fibres below the injury, in an exactly similar manner. A suture so passed will cut out much more seldom. In suturing the skin the suture described in Chapter II will be found useful. (See page 15.)

It is quite possible to nurse most of these injuries with the patient lying on the back, with the spine fully extended, provided that a proper splint, which prevents friction upon the back, is used. The best splint for this purpose is the plaster bed, and as this is useful for all injuries of the spine, it deserves a special description.

Plaster-of-Paris Beds.—In making a plaster-of-Paris bed the patient should lie upon his face upon a table, with the spine straight, the arms spread out at a right angle, the elbows fully flexed, so that the hands lie under the chin, which should be supported upon them. The scapulæ must be made to lie as flat as possible. The position of the spine and head must be adjusted to exactly that in which it is desired that the patient shall lie subsequently, as the finished bed takes the exact shape of the back, in the position in which it is made. As a rule, if the patient is left to himself he will keep the head extended to an extent that he will subsequently find uncomfortable, so that unless this full extension of the head is desired, as it may be in spinal caries or in injuries to the neck, this position should be

corrected. The head can be flexed more by allowing it to project beyond the end of the table.

Pieces of book muslin are torn long enough to reach from the top of the patient's head to the middle of the back of the thigh and wide enough to reach two inches beyond the deltoid insertion on each side. These are arranged in pairs in a handy position. They are larger than the actual area to be covered, but they shrink as soon as they are inserted in the plaster cream. At least two assistants are necessary; one mixes the plaster, the other receives the strips of muslin, stretches them out, and assists the surgeon in applying them to the patient's back.

The patient's head should be enclosed in an indiarubber cap, his back is slightly greased with vaseline or oil. Then, all being ready, a large bowl of plaster-of-Paris cream is mixed, according to the directions that will be found in the chapter on plaster-of-Paris technique. As soon as the cream is well mixed the first pair of muslin pieces are immersed in it, being held carefully at one end so as to prevent their getting out of alignment with each other. The excess of cream is got rid of by running the muslin lightly through the fingers as it is removed from the plaster. This pair of pieces is stretched out carefully, the surgeon holding the two lower corners, the second assistant the two upper corners. The assistant lays his end upon the top of the patient's head, the surgeon stretches out the muslin and lays his end upon the buttocks. The muslin is then carefully smoothed over the whole back and sides. In order to make this first piece lie smoothly it is necessary to slit it on either side opposite the neck and opposite the axillæ. The second pair of pieces of muslin has meanwhile been immersed, and is in turn handed to the surgeon and assistant. Again the assistant lays his end upon the top of the head, but the second and subsequent pieces are given a fold opposite the neck and opposite the axillæ, so that the muslin lies in folds on the back of the neck and shoulders, and can be spread into the sides of the neck and into the axillæ without cutting. Pieces are then quickly immersed in the cream and applied in the same way until about twelve pairs of pieces have been applied. By this time the cream will be thickening, so that the latter pieces hold much more plaster than do the earlier. Usually twelve pairs of pieces will make a bed of sufficient strength, but this may leave the back of the neck and the lower end of the bed weak. It is as well to strengthen these parts by putting on additional smaller pieces of muslin between the layers. If the cream sets before the bed has been made sufficiently thick, a second bowl must be mixed and additional layers applied. The last layer should be applied

without folding, cutting slits opposite the neck and axillæ as with the first piece. Throughout the whole time the pieces of muslin must be well smoothed down one upon the other, so as to press out air bubbles. When the last layer has been applied the whole must be well smoothed down and moulded on to the patient's back.

When the plaster has completely set, it is lifted off the patient's back and at once trimmed up. The inside should be inspected for any slight projections, which can be smoothed down by pressure. The edges are cut away and the lower end cut across at a level which will suffice for nursing purposes. The bed is then put aside in a warm, dry place for a day to dry. It is completed by the fixation of a cross piece of wood behind the shoulders upon which it then rests. A lining consisting of a layer of gamgee tissue is the best covering on the inner side. The patient can be secured in the bed by bandages, or webbing straps can be fastened into the plaster after it is made by covering them with a few additional strips of muslin wrung out of plaster cream. Such a bed fits the patient accurately, and as the sores which patients develop from lying upon a splint are practically always due to friction from the imperfect fitting of the splint, it is found that a patient can be nursed upon such a perfectly fitting bed with comparatively little attention to the back. After the operation of bone-grafting of the spine, I have frequently left a patient lying upon a plaster bed for from four to six weeks without once turning him over to inspect the back.

After operations upon the back, in which the wound has been completely or almost completely sutured, the patient can practically always be nursed upon such a bed. He should be turned over when it is necessary to inspect the back or to dress the wound. The bandages should be unfastened, and the whole patient and bed lifted and turned completely over, until he lies in the position in which he was when the bed was made. The bed can then be lifted off. When the dressing is completed the bed should be replaced and the patient turned on to his back again. This turning should be done as seldom as is necessary. As already stated, it may be possible to leave the patient on his back for weeks without turning him at all.

When there are wounds of the back which are very septic and which require frequent dressing, the use of this type of bed may be impracticable. In such cases a similar bed may be made to fit the front of the trunk and thighs, so that the patient lies upon his face. This position is, however, very uncomfortable, and nursing is difficult, so that it should be adopted as seldom as possible.

Concussion Injuries of the Spine.

When a man has been flung some distance by an explosion, or has been buried, he often sustains a serious injury to the spine, without the occurrence of any fracture or dislocation. In these patients the spine usually takes up a position of flexion from the first, sometimes with a tilt to one side added. The patient lies curled up in bed or sits with the shoulders bowed. When he gets up he walks with an extreme stoop, the whole spine being rounded and the hips flexed. In extreme cases the head may be level with the pelvis. It is difficult here to separate the organic element from the functional condition, which is undoubtedly often grafted upon it. We must presume that in the first place there has been some severe contusion, possibly of the vertebral column itself, possibly of its muscles, and that there has perhaps been an actual rupture of some of the vertebral ligaments. Later, however, it is clear that the flexed position, at first assumed because it is the easiest, has become habitual, that, given sufficient will power, the patient could overcome it. In other words, a position which was at first assumed because of pain, has remained as a functional deformity.

The risk of this sequence indicates the proper line of treatment. The flexed position of the spine should be overcome at the earliest possible moment. The patient must be induced to lie flat, with the spine fully extended until such time as the initial pain has subsided and he is able to assume the upright position by his own muscular effort. In fact, the spine, consisting of a series of joints, must be treated upon the same lines as are the other joints. When injured it must be rested in a standard position until the acute symptoms have subsided. And the standard position is one of full extension.

When a patient who has sustained such an injury to the spine is made to lie flat upon his back, he will at first complain of severe pain. Gradually, however, the spine will become extended as the result of the weight of the body. During the change of position the pain may be great; when, however, full extension is reached it will gradually pass off. The proper line of treatment then is to allow the spine to extend gradually in this way, and then to keep the patient flat upon his back. If there is any difficulty in keeping him in this position, because, for example, he turns upon his side and curls up, a plaster bed should be made in which he can lie.

Functional Deformities of the Spine.

Several varieties of functional deformity of the spine have already been mentioned, so that it is only necessary here to recapitulate

the conditions most frequently met with. As with functional conditions of other parts, there is in nearly every case some initial organic lesion, which has started the habit, the latter persisting after the original condition has cleared up. In this respect these functional deformities of the spine as met with in military surgery appear to differ from the hysterical deformities of the spine met with in civil practice, usually in young women. But, as the chief types of hysterical deformity correspond almost exactly with those met with in military work, it is probable that in them also there has been some slight initial lesion which has induced the position, which afterwards becomes habitual.

Fig. 125.—Fracture of the spine, with a slight kyphosis at the level of the fracture (lower dorsal), and with a well-marked lateral tilt of the whole spine to the left. This tilt extends below the level of the fracture and is therefore not due to a lateral displacement at the site of the injury, but is functional.

The most frequent functional deformities of the spine are—

1. The lateral tilt of the spine, with adduction of the hip on the opposite side, seen in patients who have walked for a long time with crutches. The patient walks upon the toes on the affected side, adducting the hip and raising the pelvis. The spine tilts towards the opposite side, so that a fold appears in the lumbar region, and in severe cases the ribs and crest of the ilium may meet. This type corresponds to the most frequent type of hysterical deformity met with in girls.

2. A lateral tilt of the spine towards one side, without any adduction of the hip or raising of the pelvis. This type follows injuries of the spine, either simple concussion, or perhaps a fracture. In either case the cause may have been that after the original injury the most comfortable position has been this tilted one, which has been adopted and kept up after the injury has recovered. In fractures it must be remembered that the tilt may have been originated by a lateral displacement of the upper vertebræ upon the lower at the site of the fracture, so that the lesion is in a sense organic. It will generally, however, be found that the deformity has an added functional element, which can be cured with comparative ease.

3. Flexion of the spine, usually after concussion injuries, as described in the previous section. In addition to these it is not

uncommon after fractures of the spine to find a general kyphosis, in addition to a forward angulation of the spine at the site of the fracture. The latter is organic, due to the actual displacement of the vertebræ upon each other; the former is functional, due to the flexed position which the patient has been allowed to assume during the consolidation of the fracture.

The treatment of all these classes must be by persuasion and re-education. In the first class it is usually as well to start by examining the spine and hip under an anæsthetic, in order to make sure that there is free movement. The same method may be necessary in the third class if there is any doubt about the mobility of the spine. In organic injuries, such as fractures, it is important first to make sure that the spine is strong, and that the condition is not due to a persistent dislocation; this can be done by clinical and X-ray examination. Then, if there is no evidence of an organic cause for the deformity, the patient may be treated by educational exercises. If there appears to be a persistent dislocation as an explanation of an antero-posterior curvature, or a lateral angulation of the spine as an explanation of a lateral tilt, it will be necessary to start by fitting a suitable support to the spine to enable it to consolidate before exercise treatment can be carried out.

Fractures of the Spine.

Fractures of the spine and dislocations of the spine have a twofold surgical interest. In the first place the vertebræ which are actually displaced, or the fractured portions of them, require reduction into their proper position, if this is possible, and fixation until consolidation has taken place. In the second place the complications due to injury to the spinal cord and its nerves have to be diagnosed and treated. Cases of injury to the spinal cord and nerves in spinal fractures which occur in military surgery differ in no essential details from those of civil practice. They are adequately treated in surgical text-books and have not come specially under the care of the military orthopædic surgeon. Therefore they will be passed over here. On the other hand, the treatment of the fracture or dislocation itself seems to have been greatly neglected. It would seem to be obvious that a fracture of the spine requires reduction and fixation, just as does any other fracture, yet it is almost the rule to find that such fractures are simply put to bed and nursed without any attempt to improve the position of the fragments or to fix the spine. Simple fractures without any nerve complications are by no means uncommon, and it may be said that all such should recover with little deformity or disability if they are treated upon proper mechanical lines.

In a recent fracture of the spine the first step should be an attempt to reduce or to improve the deformity by extension and manipulation. This can be safely done under an anæsthetic, the spine above and below the lesion being subjected to steady continuous traction, assisted by direct pressure upon the angle which is generally present at the site of the injury. The best possible position having been secured, the patient should be placed upon a plaster bed and kept there for a month to six weeks. The spine should then be supported by the application of a plaster-of-Paris jacket, in which the patient commences to walk. As a rule he should not be allowed to dispense with support until three months from the time of the injury. In cases seen at a later stage, perhaps three or four weeks after the injury, it will generally be useless to attempt to improve the position by traction or pressure under an anæsthetic. In these, if there is a considerable angulation of the spine, an attempt may be made to improve this by the following method.

The patient is laid upon his face and a plaster-of-Paris bed made as already described. He is put to lie in this, but additional padding of felt is placed in the bed opposite the point of deformity. This padding keeps up a continuous pressure upon the spine which may reduce the angle very considerably. The padding must not be placed exactly over the projecting angle of bone; if it is, a pressure sore will almost certainly be produced. It should be fitted at the sides of the projection, so that it exerts pressure upon the erector spinæ muscles at the side of the spine and only indirectly upon the spine itself.

The actual injury in a fracture or dislocation of the spine is a variable one, and the ultimate strength of the spine must depend upon the nature of the injury. In the fractures of the lower dorsal and lumbar region which are unaccompanied by injuries to the cord there is usually some crushing of one of the vertebral bodies with a fracture of the articular processes, or perhaps a dislocation of these. If the articular processes are not completely dislocated, a very fairly firm consolidation of the injured part may be expected, the vertebræ uniting either by bone or by dense fibrous tissue. When the articular processes have been dislocated from each other firm union is less probable. In the case shown in Fig. 126 there was a complete dislocation of the articular processes of the twelth dorsal and first lumbar vertebræ. Six months after the original injury the patient was unable to sit upright, there was a very great angular deformity, which increased immediately the spine was flexed. It was clear that there was no union between the dislocated vertebræ. No cord injury had been present, and no treatment had been carried

out. The patient was suspended by the head in order to straighten the spine as much as possible, and a spinal corset of plaster of Paris

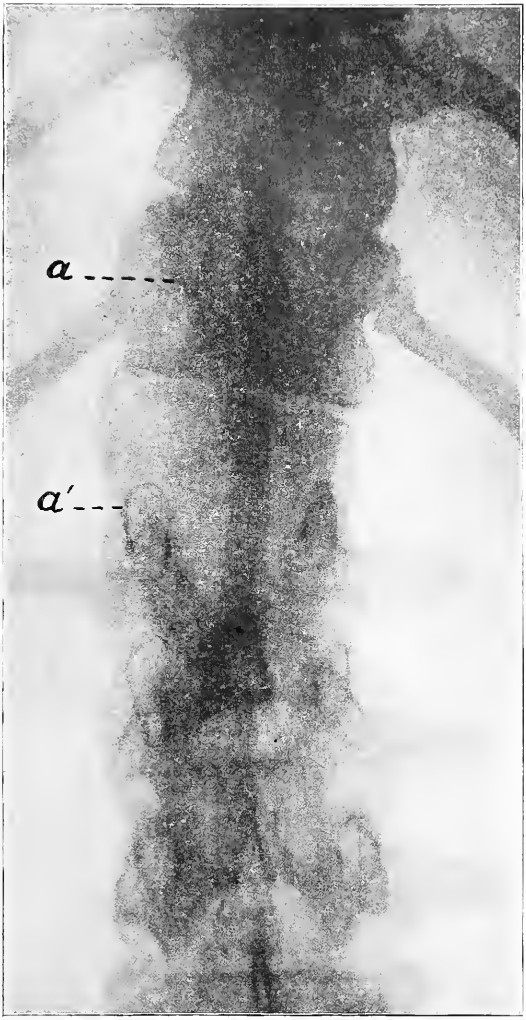

Fig. 126.—Fracture of the spine with dislocation of the articular processes of the twelfth dorsal and first lumbar vertebræ. *a* and *a′* mark these articular processes, which are separated by about $1\frac{1}{2}$ inches. The graft of bone which was inserted to unite the spinous processes of the last two dorsal and first two lumbar vertebræ can be seen in place.

extending from the pelvis to the neck applied. This was kept on for eight months, at the end of which time the patient was able to hold herself upright without it. It was, however, found that unless

a support was worn the deformity in the spine at once increased; a removable corset was therefore fitted. Later, the patient wished to dispense with the wearing of a special support. An X-ray photograph showed that the articular processes of the affected vertebræ were still completely separated from each other; it was decided, therefore, to insert a bone graft which would unite the spinous processes of the affected region. This was carried out, a graft about seven inches long being taken from the tibia and inserted between the split spinous processes of the eleventh and twelfth dorsal and first and second lumbar vertebræ by Albee's method. After time had allowed of proper union of the graft the patient was able to stand, walk, and carry out all her ordinary work without support of any sort.

Fixation of the spine in plaster of Paris is not in any sense a difficult procedure if certain principles are remembered. In the first place, the patient must be held in the desired position whilst the plaster is applied; in the second place, the plaster must be applied uniformly and evenly, and carefully moulded upon the trunk so that it fits accurately and is not tight in some places and loose in others; and finally, as the plaster is to act as a support to the upper part of the trunk, it in turn must have some base of support. It must be moulded carefully round the crests of the ilium, upon the upper edges of which it should rest.

For the application of a simple retentive plaster the best position is that with the patient suspended. A sling should be fitted under the occiput and chin and the required degree of tension applied. It is not as a rule necessary to lift the patient off the ground, nor is this desirable in an adult, for the discomfort is usually too great to allow the suspension to be continued for a sufficiently long time to enable a good plaster to be applied. It is best for the patient to stand, the head being lifted sufficiently to make it necessary for him to stand upon his toes. If he is unable to stand he may sit upon a high stool. The standing position causes a lordosis, which may or may not be desirable. The shoulders should be kept down by giving the patient bars to grasp at a suitable height.

For a simple retentive plaster it is only necessary to fit a stockinette vest under the plaster; if, however, much extension is being placed upon the spine, the pressure upon the hips will be considerable, and it is as well to fit a piece of felt around the crests of the ilium. A pad of non-absorbent cotton wool should be placed outside the vest over the epigastric region; this is subsequently removed. It should not reach below the umbilicus. If there is a sharp angle in the spine a pad of felt should be fitted around it.

Plaster-of-Paris bandages are applied uniformly around the spine and over the shoulders, being drawn just tight, without exerting any special pressure upon prominent points. The plaster must be moulded upon the trunk as it is applied. It should reach down as far as the sacrum, the great trochanters, the fold of the groin and the pubes. When sufficient has been applied the whole must be well moulded, taking care to mould around all bony points. Thus pressure must be made upon the lumbar regions above the iliac crests, so that the plaster fits in here and so gets a support upon these crests. It must be specially moulded above the anterior superior spines of the ilium and on the lower abdomen above the pubes, where it should be specially strong, also around the clavicles and spines of the scapulæ.

When the plaster has set, it should be trimmed with a knife. At the lower edge it should be cut at the level already mentioned, making sure that there is sufficient freedom of flexion at the hips to enable the patient to sit down. The arms and neck should be trimmed just sufficiently to allow freedom of movement. A considerable opening should then be cut in the front, ∧-shaped above, with the apex over the lower part of the sternum, the lower ends of the ∧ being joined by a cross cut about the level of the umbilicus. Through the opening thus made the cotton wool is removed. The front of the case depends upon the hold that it secures upon the top of the sternum and upper ribs above and upon the pelvis, and if possible upon the pubes below; the part over the lower chest and upper abdomen has been deliberately kept loose by the insertion of the cotton wool so as to allow room for breathing and for abdominal movements. If there is a sharp angle in the spine it may be as well to cut a small window over it, trusting to the hold upon the muscles and ribs around rather than to that upon the angular projection itself.

The application of plaster cases to the spine by other methods, and the application of plasters which include the head are more complicated, and for these practical demonstration is really essential.

CHAPTER XVII

SPLINTS AND SURGICAL APPLIANCES

A SPLINT is used to maintain a limb, or a part of a limb, in a fixed position. In addition, it may be used as a means of gradually altering this position by the exertion of a continuous force. Thus, in a recent fracture a splint may be applied so as to produce lateral pressure upon one fragment and gradually force it into proper alignment, or it may be assisted by the use of extension upon the distal fragment, so that the continuous force thus exerted may bring the fragments into their proper position. The use of splints in the treatment of recent fractures is a subject which requires a volume to itself, it will therefore only be alluded to here incidentally; but the position of fixation of the joints above and below a fracture has important results upon these joints, which greatly affect the after-treatment. This position of fixation of joints, both in cases of fracture and in other injuries, affects the return of function in the joint perhaps more than any other item in the early treatment.

Certain principles in the splinting of joints have been already mentioned in the chapter on the treatment of stiff joints. It will be as well to recapitulate these here.

1. There is an essential difference between cases of fracture of the shaft of a long bone and cases of fracture into a joint, or of other injury to the joint itself. In fractures of the shaft of a bone, not involving the joint, the first essential is fixation in such a position as will bring the fragments into proper alignment. In fractures into a joint, the after-effect upon the joint must be remembered. For example, a fracture of the shaft of the humerus may be safely treated upon a straight Thomas splint, but if the fracture extends into the elbow-joint, fixation in this position may result in ankylosis of the elbow in the fully extended position, thus leaving a great disability unless a further operation is undertaken.

2. There is as important a difference between injuries of a joint and injuries of the structures around the joint, particularly if the wound is infected. In an infected wound of a joint ankylosis is to be expected, and fixation should be carried out in that position in which ankylosis gives the best functional use. In a wound of the

soft parts it may or may not be necessary to fix the joint. Whenever possible a certain amount of movement should be allowed, but this movement should be gentle and active. When it is necessary to fix the joint this fixation should be carried out in a standard position, regulated by our experience of the difficulties of securing the return of certain movements in a stiff, but not ankylosed joint. These positions for fixation of a joint for peri-articular injuries are not necessarily the same as those for fixation when ankylosis is expected. For example, in the forearm, if the wound does not involve the radio-ulnar joints, a return of pronation and supination is to be expected, the position for fixation is that of full supination, for this movement is exceedingly difficult to secure at a later stage. But if the forearm is allowed to ankylose in this position a severe disability results, and the best position for ankylosis is that of semi-pronation.

3. Absolute immobilisation of a joint is indicated whenever an injury has caused inflammatory changes in the joint, and should be continued until all evidence of inflammation has subsided. The definition of inflammation is a difficulty. Thus, in a simple sprain, the effusion into a joint should not be regarded as inflammatory, complete immobilisation of a sprained joint is unnecessary, and should only be carried out when there is some special indication, such as rupture of an important ligament. On the other hand, when a gun-shot wound of a joint, such as the knee, has been excised and sutured, there is usually a slight effusion, with swelling around the joint, these signs should be regarded as evidence of inflammation. Attempts to mobilise such joints before the wound has healed and the swelling subsided have resulted in disastrous attacks of acute septic arthritis.

4. The position for fixation of a joint should seldom be an extreme one, that is, it should not be one in which certain of the ligaments and muscles are put tightly upon the stretch. For example, if the knee is to be fixed in extension, it should be allowed to lie naturally upon a back splint, with a small pad to fill in the hollow at the back of the joint. It should not be forced back into a hyper-extended position in which the posterior ligament is tightly stretched. Such extreme positions are liable to leave increased stiffness. This is particularly true of the small joints such as those of the fingers. Fixation of the hand with the metacarpo-phalangeal joints and inter-phalangeal joints hyper-extended is a frequent cause of subsequent stiffness.

Simple Stock Splints.—The number of patterns of splints in use in a hospital should be reduced as far as possible, and all patterns

should be kept as simple as is consistent with the performance of the purpose for which they are intended. Where workshops capable of doing simple metal-work are available, the best material for splints is undoubtedly iron. Splints applied to a part of a limb should be made concave in cross section, so that they fit to the normal convexity of the limb. This part of the splint is made of sheet iron, varying in thickness from 18-gauge to 22-gauge: 18-gauge is stiff and resists bending, 22-gauge is easily moulded by the hand. The sections between these concave parts can be made of stouter metal bars, $\frac{1}{2}$, $\frac{3}{4}$ or 1 inch wide, $\frac{1}{16}$ or $\frac{1}{8}$ inch thick; these are bent to form all angles necessary.

Simple gutter splints are useful for a variety of purposes. They are made of sheet iron, bent into a concave gutter. They may be made of varying size from 4 to 24 inches long, and from $2\frac{1}{2}$ to 4 inches wide. These and all other metal splints last better if they are enamelled, they should be covered on the concave surface with a lining of coarse felt, which is glued in place and which projects slightly beyond all the edges of the splint.

When, as in the short and long cock-up splints, sheet metal is bent to form an angle upon which a certain amount of pressure will fall, additional strength may be obtained by rolling a groove into the metal.

Splint for the Shoulder.—The standard position for splinting the shoulder is with the arm abducted at a right angle and slightly flexed forward. The splint used is one of the modifications of the shoulder abduction splint. It consists of a flat plate, which rests upon the crest of the ilium and is shaped to fit this; to this a vertical bar is fixed which extends up to the level of the axilla and there turns outwards at a right angle, being twisted also slightly forwards; to this a gutter in which the arm rests is attached. At the elbow a second bar is fixed by a hinge joint; this has attached a second gutter on which the forearm rests. In fitting this splint it is essential that the vertical bar and the arm bar shall be the correct length for the individual patient, it is as well, therefore, that these should be adjustable. In the splint illustrated in Fig. 127 these bars are not adjustable.

When it is necessary to fix the shoulder at a different angle—for example, when ankylosis is expected—the bend at the axilla may be altered by means of a pair of hand wrenches.

Abduction splints for the shoulder may be made with joints at the axilla, enabling the angle of abduction and the angle of forward flexion to be altered. These are somewhat complicated, and are only necessary when it is desired to alter the angle progressively

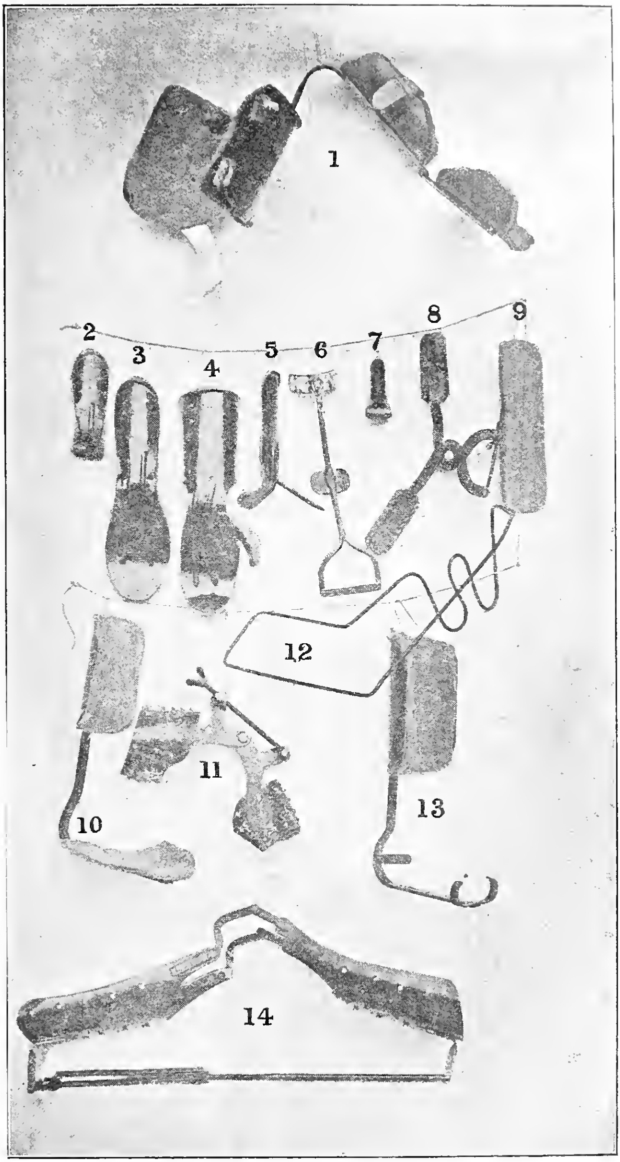

FIG. 127.—Stock Splints: (1) Abduction splint for the shoulder. (2) Short cock-up splint. (3) Long cock-up splint. (4) Long cock-up splint with thumb piece. (5) Verrall's finger-flexing splint. (6) Verrall's finger-extension splint. (7) Finger splint. (8) Turner's splint. (9) Gutter splint. (10) Club-foot shoe. (11) Rack splint for the elbow. (12) Wilson's arm splint. (13) Crab splint. (14) MacIntyre splint for flexing the knee.

as when a shoulder which is stiff in the adducted position is being gradually abducted.

Splints for the Arm.—For fixation of the arm with the elbow in the extended position the straight-arm Thomas splint is so well known that there is no need to describe it. The objections to its use in cases of injury to the elbow joint have been already mentioned. There is also an objection to retaining the elbow in the position of extension for a long period in simple fractures of the arm, for the elbow is liable to become stiff in this position and flexion may be very difficult. As soon as is practicable, therefore, the straight splint should be discarded and the arm fixed with the elbow flexed. The different varieties of Thomas humerus splint with the elbow flexed are all uncomfortable and difficult to maintain in position. Wilson's splint is probably the best splint for fixation of the arm with the elbow flexed. This is made out of a single piece of stout wire, bent into the form shown in Fig. 127. The **W**-shaped piece lies close against the side of the chest wall, and is incorporated in a light plaster-of-Paris case which surrounds the chest, being held up either by webbing slings over the shoulders or by extending the plaster down on the affected side so that it rests upon the crest of the ilium. The rest of the splint then forms two bars, which extend down the arm and forearm, one down the antero-internal aspect, the other down the postero-external aspect. The hand grasps the cross-piece at the end, the arm and forearm are suspended between these bars by slings. The shoulder is kept abducted about 45°, the elbow flexed at a right angle and the forearm pronated. The position of the forearm constitutes the one objection to this splint. It should not be used when there is any injury which may affect subsequent pronation and supination of the forearm.

When it is necessary to fix the arm in the abducted position with the elbow flexed, the simplest and most secure method is fixation in plaster of Paris. This is not a difficult procedure. It is so important that it will be specially described in the next chapter.

Splints for the Elbow.—The simplest and best splint for the elbow is the posterior angular. This consists of two gutters, for the arm and forearm, connected by a bar which is bent at a right angle behind the elbow. The angle may be altered as required.

Several devices are used for altering the angle at the elbow when the joint is stiff. When it is desired to increase flexion the simplest method is to use a collar and cuff sling. This consists of a collar of light leather which passes around the neck, and a cuff of similar material which surrounds the wrist. The two are connected by a sling of webbing with a buckle, by means of which the tension can

be adjusted. The sling is tightened so that the wrist is raised so high that the shoulder on the affected side rises. After a time the shoulder muscles tire and allow the shoulder to fall, this produces a continuous pressure upon the elbow, forcing it into a more flexed position. When the resistance to flexion is entirely muscular, a few days will ensure complete flexion. A more comfortable form of this sling is that in which the collar is dispensed with, the ends of the webbing passing over the shoulders, crossing behind, and being fastened to the trousers buttons at the back.

In similar simple cases extension can sometimes be secured by simply allowing the arm to hang without support, gravity producing extension. In cases in which the movement is painful, or in which there is much scarring, or a joint lesion, considerable force may be required to alter the position of the elbow. A racking splint will then be required. This consists of arm and forearm pieces connected at the elbow by a joint which can be racked in either direction. This requires fixation to the limb in plaster of Paris by the method described in the next chapter.

Splints for the Forearm.—The forearm should be splinted in the supinated position, except when ankylosis is expected, when fixation in the semi-pronated position is indicated. A splint consisting of lateral bars, bent at a right angle at the elbow, and with cross-pieces at the ends is useful. The upper cross-piece should be curved to lie behind the arm, the lower cross-piece is grasped by the hand.

Alteration from pronation to supination or the reverse cannot be carried out by a splint. It can, however, be managed quite simply by fixation in plaster of Paris by Verrall's method.

Splints for the Wrist and Hand.—The splints for the wrist and hand are simple but most important. Bad splinting of this part may necessitate very prolonged after-treatment, which might have been entirely avoided. In practically every case it is essential to keep the wrist extended. This applies to fractures of the arm and forearm, injuries of the wrist and hand, and injuries of the nerves of the upper limb. Stiffness or ankylosis of the wrist in the flexed position is a severe disability, and one that may tax the abilities of the orthopædic surgeon to correct.

The short cock-up splint is made from a single piece of metal; it forms a gutter in which the forearm rests, and is continued forwards in a narrow bridge, which bends at an angle of 45° at the wrist and ends in a slightly broader piece on which the base of the palm rests. The bridge under the wrist must be as narrow as possible, it should not restrict the movements of the thenar and hypothenar eminences more than is absolutely necessary. The palm-piece should also be small.

It must not extend downwards beyond the fold in the palm which marks the point of movement of the metacarpo-phalangeal joints, and again should be sufficiently narrow to allow of movement of the thenar and hypothenar eminences (see Fig. 106).

The long cock-up splint is used when it is desired to keep both the wrist and fingers extended. It consists of a gutter for the forearm, bent at an angle of 60° at the wrist and continued into a flat splint, the shape of the fingers as they lie in contact with one another. The hand portion should be curved so that the metacarpo-phalangeal and inter-phalangeal joints are held slightly flexed. This splint must be carefully applied. If it is carelessly put on, the bend which is meant to extend the wrist may come under the metacarpo-phalangeal joints and hold these fully extended, with results that may be disastrous. This splint has the defect of holding the palm in a flat position trans-

Fig. 128.—Egg splint for the hand. The hand grasps an egg-shaped mass of plaster which is cast in a mould, this is connected to a short gutter splint upon which the forearm lies by a metal bar beneath the wrist. The amount of extension of the wrist can be regulated by bending this bar.

versely, thus abolishing the transverse arches of the hand. For this reason it should be used with caution, particularly in such cases as paralysis of the median and ulnar nerves, in which these arches tend to become abolished. When it is particularly desired to retain these arches, a splint which is rounded transversely should be used.

The egg splint is designed for this purpose, being based upon some important observations of Hammond upon the transverse arches of the hand. The hand portion consists of an egg, cast in a mould out of plaster of Paris. The egg should be about $2\frac{1}{2}$ inches long, by $1\frac{1}{2}$ at its widest diameter, with a pointed extremity opposite the wrist. This is set into a metal bar, which is in turn fixed to a gutter on which the forearm rests. The bar can be bent at the wrist to any required degree of extension. Upon this splint the hand rests in a position of complete rest, with the wrist extended, the arches well maintained and all the finger joints somewhat flexed.

Finger Splints consist of a series of small gutter splints of different

sizes, each enlarged at the proximal end. They are designed for splinting the individual fingers in the extended position, and are chiefly used for straightening out flexed fingers.

Splints for the Spine and Hip.—The stock splint for the spine and hip consists of the double Thomas frame. This is so well known as to require no description. It is, however, a very difficult splint to fit and adjust, in addition it does not secure really good fixation of the spine or hip and is very difficult for nursing. For the spine, fixation upon a plaster-of-Paris bed is preferable. For the hip, when absolute fixation is necessary, enclosure of the whole trunk and limb in plaster of Paris is preferable. When it is necessary to fix a fracture of the femur in the region of the hip in the abducted position, it is simpler and more efficient to apply Thomas bed splints to both lower limbs, and to sling these to a Sinclair frame with the requisite degree of abduction.

Splints for the Thigh.—The splint used almost universally for the thigh is the Thomas bed splint, consisting of a ring which surrounds the top of the thigh, with lateral bars down either side of the limb joining each other below. This must be used with an extension of some sort applied to the leg or foot, otherwise the splint will not be kept home.

This splint may be instanced as an example of the use of a splint for the gradual correction of a deformity. In mal-union of the femur, in which the fragments form an angle convex outwards, it may be possible to correct the deformity by direct lateral pressure. The limb should be secured in the splint with an extension. A firm sling is then applied to pull the knee outwards, and a short gutter splint, well padded, is placed opposite the fracture and tightly bound to the inner bar. Direct pressure is thus made against the point of angulation, with counter-pressure above against the inner part of the ring, and below by the sling around the knee. The use of appropriate pressure and counter-pressure in this way is the essential point in the attempt to correct a deformity by pressure.

Splints for the Knee.—For simple immobilisation of the knee the Thomas bed splint may be used; or a simple gutter splint applied posteriorly may be sufficient.

When it is desired to alter the position of the knee by means of a splint, some form of rack splint will, as a rule, be necessary. In slight cases of flexion, however, direct pressure upon the front of the limb may be sufficient. When the patient is in bed, a Thomas bed splint may be applied, with slings behind the thigh and leg, and direct pressure made upon the thigh immediately above the knee and upon the tibia immediately below it. When the patient is up and about,

a Thomas caliper splint may be used in the same way. The pressure should not be made directly over the patella, as a sore is liable to result.

When the knee is considerably flexed and extension is desired. Turner's splint is the best. This consists of metal plates which are applied to the sides of the thigh and leg, being fixed in position in plaster of Paris. Opposite the knee these plates are joined by bars which form a hinge, placed eccentrically in front of the joint. Because of the eccentric position of this joint, when the rack is turned so as to extend the knee there is also a pull submitted to the leg-piece, tending to distract it from the thigh-piece and so to keep the joint surfaces at the knee apart. A direct force is thus exerted which tends to extend the knee without producing pressure of the articular surfaces against each other.

This splint will satisfactorily extend the knee to an angle of about 160°, it will not, however, extend it fully. Full extension is more readily obtained by direct pressure upon a Thomas's splint or upon a back splint.

In cases of old fracture of the femur with resulting stiffness of the knee the problem is usually that of starting flexion of the knee, *i. e.* of altering the position of the knee from the fully extended position to a position of partial flexion, so that eventually the range of movement thus proved to be present may be obtained. Turner's splint is not suitable for securing flexion in this way. The eccentric position of the joint, which causes distraction of the joint surfaces when the knee is extended, will force these surfaces together when a knee which is already extended is forced into flexion. The best splint for use to force flexion is the MacIntyre splint. For this purpose the splint is made without any foot-piece or back support. and with its surfaces roughened for inclusion in plaster of Paris. The leg and thigh are fixed in plaster, the splint being included, and the limb gradually racked into the required degree of flexion. If it is desired to obtain a large movement of flexion it may be necessary to alter the screw in the rack during the process, for any one screw must necessarily allow of only a limited angular movement. The details of fixation of the rack splints will be described in the next chapter.

Splints for the Ankle and Foot.—The foot is practically always splinted with the foot at a right angle to the leg, and neither inverted nor everted. The right-angled clubfoot shoe is the simplest and best splint, it consists of a gutter for the back of the leg, and a footplate, connected by a bar, which is set away from the back of the heel, which it must not touch. When wounds around the ankle and tarsus require dressing the crab splint may be used. In this the

foot-plate is replaced by a skeleton band. It does not give such secure fixation. When immobilisation of the ankle and tarsus is required, fixation in plaster of Paris is the best method.

When the right-angled position of the foot is desired, and it is necessary also to fix the knee in extension, the long back splint with foot-piece may be used. This consists of gutters for the thigh and leg and a foot-plate, the three being connected by a posterior bar, which is slightly bent at the knee to allow for the hollow in the popliteal space and set away at the heel in the same way as is the clubfoot shoe.

Surgical Appliances

A surgical appliance may be defined as a piece of apparatus which is worn for a considerable time upon the trunk or upon a limb, and which acts as a mechanical support in which the functions of the part are to some extent preserved. There can be no complete separation of splints from appliances. For example, a short cock-up splint forms a most useful appliance in cases of musculo-spiral paralysis, because by keeping the wrist extended it allows of considerable functional use of the hand. On the other hand, a moulded leather appliance for a flail elbow which keeps it in the flexed position, and allows of functional use of the limb, also by splinting the elbow and supporting the biceps, enables the latter muscle to recover tone. Roughly we may class as a surgical appliance anything that assists in functional use. Generally, appliances are made individually for the patients, whereas splints are taken from stock.

In designing a surgical appliance it is first necessary to determine exactly what it is that we wish to do. Do we, for example, wish to relieve a limb from weight-bearing? If so, upon what point are we to carry the weight? Do we wish to fix a joint completely? Or do we wish to allow limited or complete movement? Do we wish to give lateral support to prevent abnormal mobility of the joint? It would obviously be difficult in a small space to describe all the problems that may be met with in designing appliances. It will be best to take a few examples which will serve to illustrate principles upon which appliances may be designed.

The Caliper Splint.—When a fractured femur has consolidated, so that no mobility at the site of fracture remains, the new bone is not at first strong enough to bear the weight of the body. If it is subjected to this it may break, or more frequently it may bend. It is necessary at first to support it and to relieve it of weight-bearing. This can be done by the simple method of carrying the weight through a ring, which fits closely around the top of the thigh, on to two lateral

uprights of steel which end in a socket in the heel of the boot. Provided that the ring fits closely beneath the tuberosity of the ischium, which must rest upon it, and that the lateral steels are made of such a length that the heel does not quite reach the bottom of the boot, the whole of the body weight will be carried to the ground through the appliance. The ring should be kept low on the inner side, so that it does not press upon the perineum, on the outer side it should rise to a level just above the top of the great trochanter. It should be well padded, specially at the back, where the tuberosity of the ischium rests upon it. The socket in the boot is made as shown in Fig. 130. It is placed obliquely, so as to turn the toe out a little. The simplest method of securing the limb in the splint is by means of a broad leather sling at the back. The thigh and leg are pressed back against this by a broad, stiff plate above the knee and by a narrow band below the knee, each of which is buckled back to the side steels.

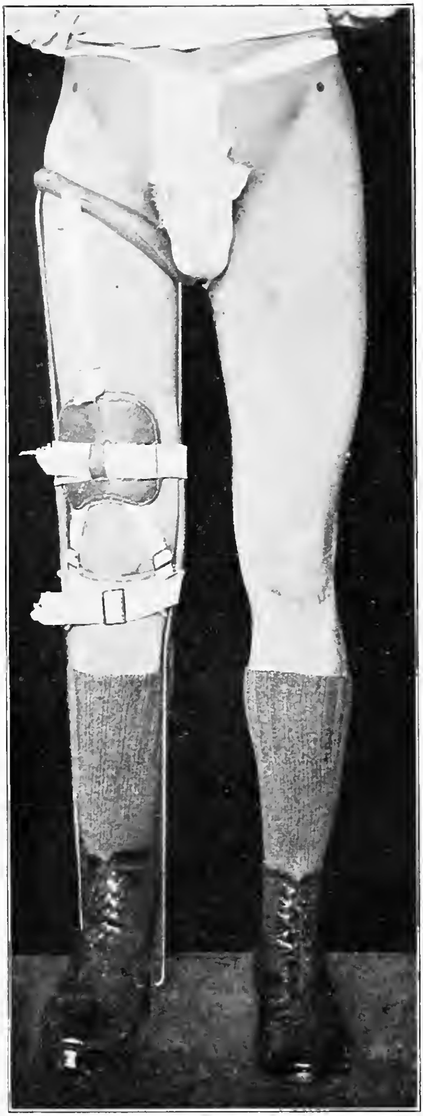

Fig. 129.—The Thomas caliper splint.

This splint may be made to serve other purposes. It may be used to keep the knee straight in the extended position, or to force it straight if it is flexed; or it may be used to give lateral support to the limb without relieving it of weight-bearing. In the latter case the side steels are made of such a length as to allow the heel to reach the ground. In any of these uses the splint allows the limb to function, the patient walking with a stiff knee.

Most of the elaborate walking splints designed for ambulatory treatment of fractures of the lower limb are simply elaborations of the caliper splint. The Hessing walking appliance may be taken as a type of these. For its manufacture a plaster-cast of the whole limb is necessary. Upon this leather pieces are moulded to fit (1) the top of the thigh, (2) the leg, (3) the foot. The first-named piece is fitted closely beneath the tuberosity of the ischium, which rests upon or within it, all three pieces are strengthened with metal strips. The three leather pieces are united by lateral steels which allow of adjustment for length. A fitting around the ankle like a spat can be attached to the foot-piece and pulled down, extension being thus applied to the limb. Such extension, however, can only take effect when the knee is extended; as soon as the knee is flexed the splint acts as a lateral support only.

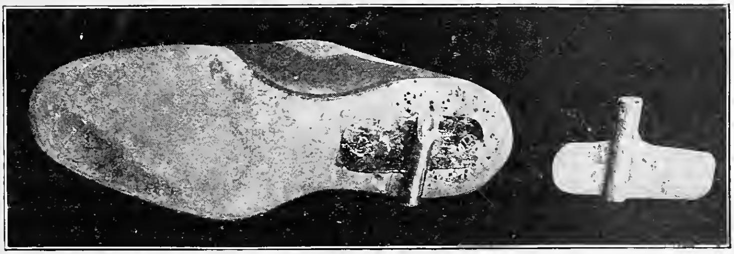

FIG. 130.—Method of fixing the socket in the boot for a caliper splint or for a side iron. The figure on the right shows the socket complete, that on the left the position in which it is fixed into the boot. In the latter the tube has been cut across to show a section.

Simple Moulded Leather Splints for Fixation of Joints.—In such joints as the knee and elbow, it is often necessary to secure absolute fixation. In the elbow this may be necessary because the joint is flail, or because there is a slight range of painful mobility. In the knee fixation is usually indicated for an incomplete ankylosis.

A moulded leather splint is made upon a plaster-of-Paris cast of the limb taken by the method described in the next chapter. When the positive cast has been obtained it still requires preparation before it is ready for the leather worker. It is necessary to accentuate any bony prominences, so that the finished splint may not press upon them; and it may be necessary to pare down the plaster over soft parts in order to make the splint fit more tightly. For example, when a cast has been taken of the thigh, leg and knee, the tubercle of the tibia and the head of the fibula will require accentuation, the calf and back of the thigh must be pared down. Then, when the cast is complete and is thoroughly dry, it is bound with a

single layer of muslin bandage made to adhere with thin starch, and it is then ready for the leather blocker. The outlines of the leather splint should be drawn upon the cast by the surgeon, the line down which it is to open indicated and any steel strengthening marked. Good stout sole leather is stretched wet upon the cast, well worked on until it lies quite flat and even, and nailed down until it is dry. The case thus made is fitted upon the patient, trimmed down, lined, and lacings attached.

It is often necessary to add strips of steel to strengthen the splint. Many instrument makers fix these in the wrong place. The strain to which they will be subjected should be considered and the steels attached in such a way as will give the best resistance to this. For example, in a knee splint a piece of steel is often fixed down the back of the knee. The strain here is one which tends to flex the knee. If the steel is placed down the back of the limb the flat side of this steel is opposed to the pressure, so that the resistance is only that of about $\frac{1}{16}$ inch of steel. If instead strips of steel are fixed down the sides of the splint, the strain comes edgeways upon these, and the pressure is resisted by the full width of the steel, perhaps three-quarters of an inch. Similarly in an elbow joint a posterior steel is of little use; one or two lateral steels are much more serviceable.

The Knee Cage.—Appliances which are fitted to the knee to allow movements of flexion and extension, but to restrain abnormal lateral or antero-posterior mobility, or to abolish rotation in the flexed position, or to limit the range of flexion, may be classed together as knee cages. Many of the knee cages in use are inefficient. A knee cage should secure a wide hold upon the thigh and leg, and should be carried down to the boot, so that the knee joint is kept at a fixed level. When the appliance does not reach the boot it almost invariably tends to slip down, so that the steel knee joint does not remain accurately centred opposite the centre of movement of the knee.

A knee cage is best made upon a plaster cast of the limb. Upon this the centre of rotation of the knee joint should first be marked. This is situated well back upon the most prominent part of the condyles of the femur. This centre of movement must be somewhat arbitrarily chosen. For actually when the knee flexes the tibia glides backwards round a surface which is not strictly circular. The centre of movement alters, it is further back for the more extreme degrees of flexion than it is for the initial movement. However, if spots upon the posterior part of the prominent condyles of the femur are chosen, a centre of movement is obtained which will serve for practical purposes. The extent of the thigh corset of leather is next

marked out. This should extend for five inches or more up the thigh, its lower edge must be kept high at the back, to prevent its blocking flexion of the joint. The lateral steels should be placed down the sides of the thigh and curved backwards above the knee, in order to bring them opposite the centre of movement. The leg corset should also be five inches in length, and must be cut away at the back above, again to prevent blocking of flexion. Lateral steels should be carried down from the knee joint, the inner steel stopping at the lower end of the leg corset, the outer extending to the heel of the boot, where it fits into a socket similar to that used for a caliper.

Such a simple appliance, with fully mobile joint at the knee, will prevent lateral or antero-posterior mobility, but will not limit the degree of flexion permitted. In order to do this a stop must be inserted in the knee joint. This stop may, if desired, be made adjustable, so that the amount of flexion allowed may be varied.

Leg Irons.—Simple leg irons are much required for the support of the ankle, and for use in cases of paralysis of the sciatic nerve or of its branches. A single iron may be fitted upon the inner or outer side, or irons both sides may be used. The iron should consist of a straight rod, or of one which is curved outwards slightly to clear the malleolus; to its upper end is fitted a steel band which encircles the posterior half of the leg, its lower end fits in a socket in the heel. The upper band should encircle the leg about an inch below the head of the fibula, it must not press upon the latter point. This band is enclosed in leather, with a buckle in front.

A single iron on the outer side is used to throw the foot on to its outer side, *i. e.* to correct a valgus deformity of the ankle. An iron on the inner side is used to correct a varus deformity. It is best to thicken the boot on the inner side when fitting an outside iron, and to thicken it on the outer side when fitting an inside iron. This thickening, so far as the heel is concerned, should be placed above the socket in the heel, so that the foot is set over above the iron. A T-strap is usually attached to the side of the boot opposite to that on which the iron is fitted. It buckles around the ankle and iron, thus pulling the foot over towards the iron. A T-strap fixed to the inner side of the boot and buckled around an outside iron, thus corrects a valgus deformity, and is called a valgus T-strap. One fixed to the outer side of the boot and buckling around an inside iron corrects a varus deformity, and is called a varus T-strap.

When a double iron is fitted, the boot is thickened on the inner or outer side according as it is desired to correct a valgus or a varus deformity, and an appropriate T-strap is attached. Whenever there is footdrop and elevation of the toes is necessary a double

iron should be used. The simplest method of elevating the toes is to attach a coiled steel spring to the boot at the lowest part of the lacing, the upper end of this spring is fixed to a forked leather thong. the ends of which are attached to the inner and outer sides of the calf band. A buckle in this leather thong allows of adjustment of the spring.

Simple toe-elevating springs are often used without any irons. The forked leather thong attached to the top of the coiled steel spring is simply attached to a calf band of leather or webbing. Such an appliance cannot be really effective, for there is nothing to prevent the calf band from slipping down except the prominence of the calf

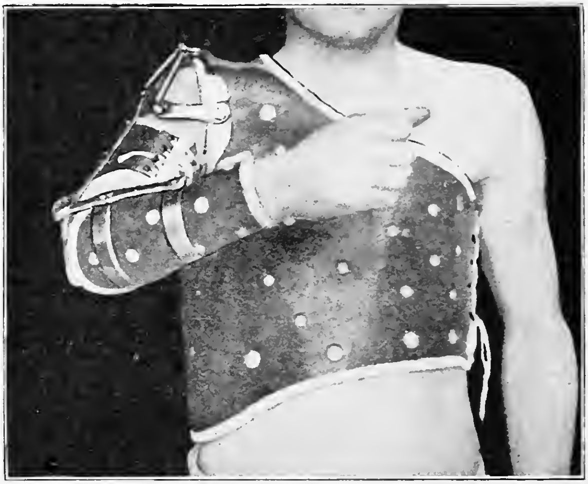

Fig. 131.—Leather and steel appliance for a flail shoulder.

itself. A simple spring of this sort is only suitable for the very slightest degrees of dropfoot.

Appliances for the Shoulder.—Appliances which are designed to fix a joint absolutely are a simple problem either in the upper limb or in the lower limb. The moulding of a case of leather or other material around the joint and the region above and below it will always be efficient if the case is carried sufficiently far in either direction. Thus, when it is desired to fix the shoulder, a leather case must be fitted which encloses the chest, shoulder and arm. If the shoulder is flail from loss of the head of the humerus, even a case of this extent will allow an upward and downward excursion of the bone. If this is to be stopped it will be necessary to carry the appliance below the elbow and to prevent full flexion of this joint.

When it is desired to fit an appliance to the shoulder which will

allow mobility, but will control the movement, the problem is a difficult one. The appliance shown in Figs. 131 and 132 was designed for a case of flail shoulder with loss of a considerable part of the upper end of the humerus; it could be used also for an ununited fracture of the humerus. The appliance takes its support from a leather cuirass which surrounds the upper part of the chest. Movement of the shoulder joint in two planes is permitted by the insertion of a double joint, the details of which are shown in Fig. 132. The upper joint allows abduction and adduction of the shoulder, the

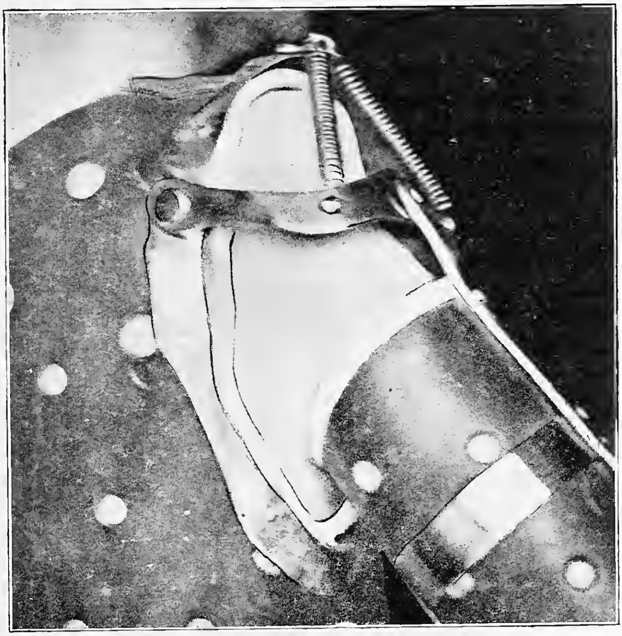

Fig. 132.—Details of the shoulder joint of the appliance (see text).

lower joint allows movement forward and backward. The steel from this lower joint is continued into the outer side of the arm case. A simple hinge-joint is inserted at the elbow, allowing flexion and extension of the joint. A spring is attached at the shoulder to hold the arm abducted to a moderate degree. This was necessary for this particular patient, because abduction of the shoulder was completely abolished. Rotation at the shoulder joint is not allowed.

This appliance may be taken as an illustration of the principles of designing any complicated appliance.

1. First determine exactly what mechanical purposes the appliance is to fulfil.

2. Fix the appliance by a proximal piece which attaches it to the body in such a way that any strains to which it is subjected will not displace it.

3. Enclose each segment of the limb sufficiently to prevent movement of the case on the limb as the joints move.

4. Place the steel joints as nearly as possible opposite the centres of movement of the natural joint, and allow mobility in the direction in which normal mobility takes place.

Failure to appreciate the importance of some of these principles will be mentioned in considering the design of appliances for flail elbow and for dropwrist.

Appliances for Flail Elbow.—In many cases of flail elbow the best appliance is a moulded leather splint which encloses and fixes the joint. This is simple, it renders the arm and hand useful for many purposes, and by fixation of the joint in the position of right-angled flexion considerable return of power in the flexor muscles frequently takes place. When, however, there is some degree of stability in the joint and when the flexor muscles work well it may be desirable to attempt to make an appliance which allows of flexion and extension movements. This takes the form of leather arm and forearm corsets with lateral steel joints at the elbow. The difficulty in fitting it depends upon the fact that in most of these cases the condyles of the humerus have been removed. In order to keep an appliance for the elbow from slipping downwards it is necessary to mould the leather arm corset closely around the condyles, and to set the steels in against these. Unless this is done the arm corset slips down and the steel joint at the elbow fails to coincide with the natural elbow. When the condyles are missing it is impossible to secure a fitting against them, and this slipping of the appliance almost invariably takes place. The only alternative is to carry the arm corset high up on the outer side of the shoulder, over the deltoid muscle, and to attach to its upper edge two webbing bands which cross over the shoulder and pass under the opposite axilla. Even this harness will not in itself prevent slipping if the elbow is allowed to extend fully. It is better to stop extension at about an angle of 135°, so that the flexed position will prevent much slipping.

Appliances for Drop Wrist.—The design of an efficient appliance for extending the wrist, fingers and thumb in paralysis of the musculo-spiral nerve is extremely difficult. The simplest form is the short cock-up splint, which simply holds the wrist in an extended position, and so allows such use of the fingers and thumb as can be obtained by the use of the remaining muscles. It may be said straightaway that this simple appliance is also

in many cases the most efficient, and the one preferred by the patients.

Many forms of gloves, with accumulators or springs to extend the fingers, have been designed. Most of these are inefficient, for a very simple reason. The ordinary design is that of a glove with elastics attached to the posterior surface, over each finger and over the thumb; these elastics pass over a cushion placed upon the back of the wrist and are attached above to a case which encloses the forearm; the wrist may be extended by attaching additional elastics over the back of the metacarpals, and carrying these up to the forearm case, or a short cock-up splint may be used inside the glove. The difficulty in this form of apparatus depends upon the impossibility of securing a hold on the forearm which will supply a proper counter pressure to oppose the pull of the elastic. The force in the elastic which pulls the fingers into the extended position tends to pull the forearm case down the limb against the wrist. The only possible method of opposing this is to mould the case very accurately around the styloid processes of the radius and ulna. In some patients this is possible, in many the bones are not sufficiently prominent or will not stand the necessary pressure. Most gloves made upon this plan tend to slip down, and are inefficient and uncomfortable. Another defect is the tendency for the elastic accumulators to produce hyper-extension of the metacarpo-phalangeal joints; this can, however, be got over by using elastics for both wrist and fingers and adjusting the tension on each.

In France appliances of a different sort are used. They consist of a forearm case with lateral steels, and a joint at the wrist to which a small palmar plate or bar is fixed to hold the wrist extended. In some designs the joint at the wrist is simple, allowing extension and flexion only, in some a double joint is fitted so that abduction and adduction are allowed. In either case one or more springs are attached on the extensor aspect to keep the wrist extended, unless it is forcibly flexed by the flexor muscles. The fingers are held extended by thin steel springs attached to the extensor aspect of the forearm case and ending below in rings which encircle the fingers just beyond the metacarpo-phalangeal joints. These springs are made of fine spring steel, which maintains extension by resisting bending. They are not coiled. This form of appliance is mechanically good, for it does not tend to pull out of place. The objection to it is its elaboration and difficulty of manufacture, and the fact that the fine steel springs tend very soon to rust and to break. The life of such springs is a few weeks only.

In order to get simplicity and efficiency in an appliance for extend-

ing the wrist and fingers it is necessary to take a purchase from the arm above the elbow. A collar must be fitted around the condyles of the humerus, from this a short loop should hang on the posterior surface of the joint as far as a point over the head of the radius. From this point arise a series of elastic straps, each capable of adjustment in length. The distal ends of these are attached to a glove after passing through a loop on the back of the wrist. Two of the elastics are fixed to either side of the dorsal surface of the wrist, to represent the extensores carpi radialis and ulnaris, one is attached to the glove over the terminal joint of the thumb, after passing through a loop placed opposite the metacarpo-phalangeal joint. The others are fixed to the back of the first phalanges of each finger. By adjusting the tension of these several straps the hand can be held in a comfortable position and free use permitted.

Such an appliance is, of course, not very durable. The great difficulty of designing a good permanent appliance for use to extend the wrist and fingers is a strong argument in favour of tendon transplantation in cases of musculo-spiral paralysis in which the nerve cannot be sutured.

CHAPTER XVIII

PLASTER-OF-PARIS TECHNIQUE

SKILL and resource in the use of plaster of Paris is of vital importance to the orthopædic surgeon. When absolute fixation is desired no other method is so perfect as fixation in plaster. Splints of all sorts and for all purposes can be made from plaster in a few minutes, and if appliances are to be made to fit accurately and comfortably there is no method of measurement which can possibly give such good results as are obtained by working upon plaster-of-Paris casts.

The best variety of plaster of Paris for surgical use is that known as fine Italian plaster. This is not the best plaster obtainable, the very superfine varieties being unnecessary. Fine Italian plaster can be obtained in quantity at about *7s.* a cwt., therefore it is not economical to purchase it in small quantities from a chemist. Nor is it economical or satisfactory to purchase plaster-of-Paris bandages ready made. Bandages made in the hospital are far more satisfactory, and with very little instruction and practice a nurse or orderly can be taught to make bandages which are in every way superior to the bought article. Plaster of Paris keeps well if stored in tins or galvanised iron receptacles in a dry place. Its setting qualities can be improved by baking in an oven before use.

The setting of plaster of Paris depends upon a chemical combination of the calcium sulphate with a definite proportion of water. Therefore if good and regular setting is desired it is necessary to mix the plaster and water in the correct proportions. For many purposes it is necessary to mix the plaster in the form of a cream. This is best done by the following method.

A bowl with a rounded bottom is filled about two-thirds full of water. The plaster of Paris is then taken in handfuls and sprinkled rapidly and evenly over the water, handful after handful, until it just shows through the water. The mixture is then stirred from the bottom with a large spoon or with an egg whisk, until the whole forms a perfectly smooth cream; about half a minute's stirring should suffice. If cold water has been used the cream soon thickens and sets firmly in about three minutes. Warm water makes the setting more rapid, and the addition of salt to the water renders it more

rapid still. Much salt, however, makes the plaster brittle. The cream should be kept stirred until it sets, otherwise it may set unevenly. Plaster cream made in this way is useful for making plaster splints; for example, as already described, a plaster bed is made by building up strips of muslin wrung out of cream into the desired shape, and muslin or other material wrung out of cream may be used to strengthen a plaster-of-Paris case. Cream mixed by this method is also used for filling and making up plaster casts.

Plaster-of-Paris Bandages.—The best material for use in making plaster-of-Paris bandages is a book muslin which consists of about 30 to 40 strands to the inch. It should not contain too much dressing, and what it does contain should be starch and not glue. The muslin is torn into strips four, six or eight inches wide and six feet long. The two marginal strands at either side of each strip should be frayed out and removed; if this is not done these strands come loose and interfere with the easy application of the bandage. The strips thus prepared should be lightly rolled.

In charging the bandages with plaster it is essential to get a sufficient quantity of the latter rubbed into the muslin evenly without any lumps or masses of plaster being left between the layers. The bandage must be rolled quite loosely, so that water can percolate quickly between all the layers. The muslin roll should be laid upon a tray with a heap of plaster alongside, the first length of bandage is unrolled and covered with plaster which is gently rubbed off with the flat of the hand. This portion is then rolled very loosely from the extremity and the next section spread out, rubbed with plaster, and rolled in the same way. When the bandage is finished it should feel quite soft and loose, and when dropped into water it should be soaked through in a few seconds. If air bubbles continue to escape from it for a minute or so it has been too tightly rolled. When prepared the bandages must be carefully handled and should be stored in air-tight tins in which they are closely packed. If kept thus they will remain good for several weeks. When used each bandage should be carefully lifted from the tin, being kept horizontal, dropped into the water so that it is completely immersed, and then removed from the water by being grasped by either end and squeezed gently. It should not be handled in the water, nor squeezed by the middle; either of these methods tends to squeeze out the plaster.

Application of a Simple Plaster-of-Paris Case for Retention.—When it is desired to fix a limb or a part of a limb in plaster in order to maintain a position there should be no special pressure upon any one spot by the plaster. Although sores which develop inside a plaster case are often called pressure sores, they are actually almost

always caused by friction. That is, they are caused by the plaster fitting unevenly, so that it is loose in some places, tight in others. The limb is then able to move slightly inside the case, and friction over the region where the plaster is tight causes the sore. It is to a misconception upon this point that a great deal of bad plaster-of-Paris work is due. It is unnecessary to insert much padding beneath the plaster; in fact, it is perfectly safe to use the plaster bandages direct upon the skin. The general custom is to cover the skin with a single bandage of flannel or flannellette, or perhaps better to cover it with a layer of tubular stockinette. Cotton wadding is often used; the chief objection to it is that at first it forms a considerable layer between the skin and the plaster, but after a few days it packs more tightly, so that the plaster becomes loose.

The limb being covered in this way, it is held in the position in which fixation is required and the plaster bandages applied. The limb should be held in the desired position throughout. Correction of the position after the plaster is applied and before it has set is a frequent cause of plaster sores, for such alteration of position is very liable to cause a local tightness of the plaster at a particular spot. For example, if the ankle is allowed to hang in equinus whilst a plaster is applied and the foot then forced to a right angle, there will almost certainly be a local pressure over the anterior surface of the ankle, and a sore may result. The plaster bandages should be applied evenly, starting from the distal end and working centrally, and then back again. At each end three complete turns should be given, for otherwise the ends are much thinner than the central part of the plaster. Thus in applying a plaster from the middle of the calf to the middle of the thigh, three turns are first made round the calf, then the bandage is wound evenly upwards until the upper limit is reached, here three more turns are made and the bandage then wound downwards again to the lower end, three more turns here and then upwards again, until the case is sufficiently thick.

Each turn of the bandage should be kept close to the limb without being tight. If the turns are drawn tight they will constrict the limb at their margin, if they are left too loose the case will not fit snugly. The best method is to pull the bandage fairly tight, but in each turn to fold it back upon itself, in the manner shown in Fig. 138; this allows of firmness without constriction and also allows the bandage to be manipulated easily and made to run in any required direction. As each bandage is finished the whole plaster should be smoothed down and moulded on to the limb before the next is commenced. When sufficient has been applied the whole case should be moulded on to

the limb until it has set, particular care being taken to mould around all bony prominences, so that the plaster is made to fit closely around them. If this is done friction over these bones is eliminated.

A plaster case may be strengthened locally by various methods; by suitable strengthening at those points where the strain will fall the whole case can be made lighter. For example, a plaster applied to the pelvis and hip almost always tends to break in front of the fold of the groin; it should be greatly strengthened at this point. The simplest method of strengthening is by reinforcing with additional layers of plaster bandage laid in any direction, or by inserting a slab made by folding a bandage into a strip of many layers. Such a slab may be placed in front of the groin, or a bandage may be taken and run up and down for a dozen turns here. Another method which is specially useful in spinal plasters is the use of a large bowl of plaster cream, strips of muslin (doubled) being dipped into this and incorporated in the plaster case. Instead of using muslin and plaster, other materials may be incorporated. Thus in a plaster applied to the lower limb strips of wood may be incorporated. Thin strips of deal one inch wide and $\frac{1}{16}$ inch thick should be used, and they should be soaked in water for a considerable time beforehand. They will bend readily to the shape of the limb. Metal may be inserted; this is seldom necessary in a simple plaster case, but is useful when windows have to be cut or gaps left in the plaster. Metal is also almost indispensable in applying a plaster to the chest and arm. The strips of metal used should be 18 to 22 gauge, and $\frac{3}{4}$ to 1 inch wide, or when they are to act as interruptions in the plaster, metal $\frac{1}{8}$ inch thick and $\frac{3}{4}$ inch wide may be used. The pieces should be bent into the required shape beforehand, and that part of them which will be incorporated in the plaster should be tightly wrapped round with a few turns of plaster bandage; this will make it hold in the plaster more securely. Galvanised iron wire may also be used; it can be bent into the required shape readily, and it also should be wrapped round with plaster bandage to make it adhere.

When a wound upon the part to be enclosed will require dressing it is necessary to cut a window in the plaster. It is not always easy to estimate the position of the wound; a simple method is to insert one of the right-angled metal pieces used in building Verrall's supinating plaster over the wound so that one end of it projects at right angles to the surface through the plaster; this marks the point for the window, and is removed when the window has been cut.

When completed the plaster should be trimmed up and windows cut with a sharp knife. At the stage immediately after it has set plaster cuts readily with a knife. The surface should be smoothed

down well with a wet hand or with a bandage. The better the surface the longer the plaster will last in good condition.

In applying a simple plaster such as that used to hold the foot at a right angle the method is easy. But when a more elaborate application has to be made it may be necessary to think out in advance how the case shall be arranged and upon what points the weight of the limb and of the plaster will fall. For example, when the whole lower limb is enclosed in plaster up to the hip, but not including the pelvis, the weight of the limb and plaster hanging upon the hip may be considerable. The patient may find it comfortable to be relieved of this weight by a shoulder strap. A long piece of 2-inch webbing is incorporated in the posterior part of the plaster at such an angle that it passes over the opposite shoulder, a shorter piece incorporated in front carries a buckle to which the shoulder strap fastens A plaster case to fix the shoulder and to support it in a position of right-angled abduction illustrates many of the points in the application of a large plaster. The plaster should be carried down on to the hip on the side of the affected shoulder, and moulded over the crest of the ilium so that it takes its bearing upon this point. On the other side only a comparatively narrow piece of plaster is required under the axilla, for the counter pressure here is an upward one against the axilla. These two points of pressure require padding, so that pads of felt are inserted under the plaster over the hip and beneath the axilla. The whole arm and forearm should be included in plaster, which also encloses the shoulder joint, the best position being that shown in Fig. 133. A metal bar bent to the required angle is incorporated in the plaster to support the shoulder; if necessary a second bar may be added to support the forearm. The hand should be held by a short cock-up splint, which may or may not be included in the plaster.

When a plaster case has been applied to the lower limb, including the foot, it may be desired to allow the patient to walk upon the plaster. In this case a foot-plate of wood $\frac{3}{4}$ inch thick should be attached to the sole by a few turns of plaster bandages. This will protect the actual plaster case, which would otherwise quickly be broken.

Plaster Sores.—As already remarked, sores are due usually to friction or to a local pressure by the plaster which is unevenly tight. It is very rarely that a plaster case gives trouble by being too tight around a limb and constricting it. The first stage in the production of a sore is the rubbing of epithelium, which thickens and desquamates, a peculiar smell being produced. This smell becomes more pronounced after a sore forms. Whenever a patient complains of

discomfort over one part of a limb which is enclosed in plaster the possibility of a sore should be thought of. The smell may be recognised even before the skin has sloughed or ulcerated, and by removing the pressure at this stage more serious results may be avoided. When a plaster has been causing friction or constriction and has been removed the limb should be carefully wrapped up in a thick layer of cotton wool and bandaged firmly. If this is not done the sudden relief of pressure may produce engorgement of the affected area of skin, which may become gangrenous, a form of gangrene analogous to that which occurs in frost bite. When a sore has actually been produced, the first stage in treatment is to get the slough to separate. Fomentations may assist in this, or if the process is

FIG. 133.—Fixation of the shoulder and arm in a plaster case.

slow the area may be kept packed with gauze soaked in enzymol. When the slough has separated and a callous ulcer remains a dressing of calamine ointment is the best.

Removal of Plaster.—The only really good shears for cutting plaster of Paris are those known as Stille's, which actually punch out a section of the plaster. If these are not available the plaster may be cut partly through with a saw and the cutting completed with a knife. Plaster of Paris can be softened with acetic acid, or better by laying upon it pads of wool soaked in peroxide of hydrogen.

When a limb has been enclosed in plaster it almost invariably tends to swell for a time after the case is removed. This may be prevented by firm bandaging over cotton wool. The skin under the plaster desquamates extensively; if the patient is allowed to wash the limb vigorously and to attempt to get rid of all the desquamated

epithelium quickly, the skin is very liable to get sore. The skin should only be washed lightly, and then gently rubbed with vaseline or a simple ointment. Because of this desquamation it is undesirable to arrange to operate upon a limb soon after it has been removed from a plaster case. A week should be allowed for the skin to get into good condition.

Plaster-of-Paris Splints.—Splints made of plaster of Paris and muslin have the advantages that they can be made in a few minutes of any shape, to hold a limb in any position, and that they fit so accurately that it is possible to use them upon any part. For example, it is not possible to use a metal splint upon the extensor aspect of the hand unless it is made most carefully to the shape of the hand. It is quite

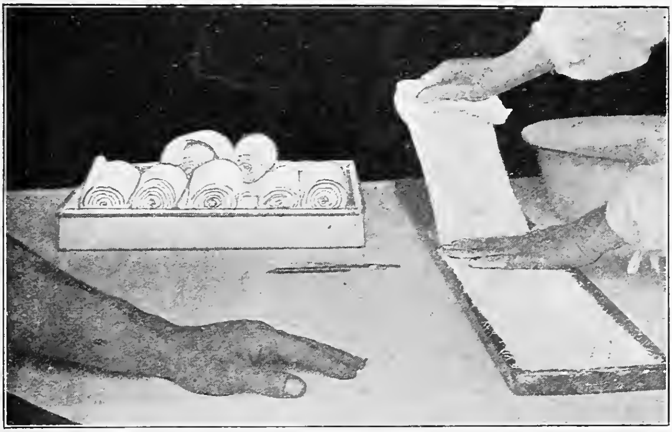

Fig. 134.—Making a plaster-of-Paris splint. Spreading the bandage to make a slab of plaster.

easy to fit a plaster splint which is moulded to all the knuckles, so that it does not press unduly upon them. Figs. 134 to 136 illustrate the method of making such a splint fitted to the dorsum of the wrist and holding the wrist extended and the metacarpo-phalangeal joints slightly flexed. Such a splint is useful for preventing the latter joints from extending again when they have been stiff in the extended position; it allows free movement to the interphalangeal joints.

The materials required are a plaster bandage of the right width, a bowl of water. a flat piece of wood, vaseline, an indelible pencil and a knife. The length and width of splint required are first measured; the bandage should be the width of the splint required or a little wider. The piece of wood is greased with vaseline and the plaster bandage, after being soaked in water, is spread backwards and forwards on it until a slab the required length is made consisting of

eight to ten thicknesses of bandage. The limb is greased and held in the position in which the splint is to fit and the plaster slab applied and held in place until it is just set, being gently smoothed down so that it fits accurately. If there is any difficulty in fitting around a joint, e. g. round the flexed elbow joint, the slab can be cut at the

Fig. 135.—Making a plaster-of-Paris splint. Applying the slab of plaster to the limb.

sides and overlapped. The overlapped parts are afterwards joined securely by additional plaster. When the slab is hard it is marked out to show the exact size of the splint and the points to which any required straps are to be fixed. It is then removed and trimmed with a knife. When it is dry it is strengthened by fixing wire or metal along the outer side; this is attached to the splint with plaster cream and tow, and covered with a few turns of plaster bandage.

Fig. 136.—Making a plaster-of-Paris splint. The slab has set, and the outlines of the splint and the position of the straps have been marked.

Webbing straps are fixed by means of these additional strips of bandage. The interior of the splint can be lined with lint, which is fixed on with starch paste after the plaster is thoroughly dry, and this lint can be turned over the edge of the splint to make it neat. Fig. 137 shows a complete splint made to support the palm of the hand and the metacarpo-phalangeal joints, allowing movement of the interphalangeal joints only.

The plaster bed described in Chapter XVI is another example of

a plaster splint, made by a different method, viz. by the use of plaster cream and strips of muslin.

Plaster-of-Paris Casts.—For surgical purposes plaster-of-Paris casts are required to serve as models upon which splints and appliances can be made and fitted. The method of making appliances upon casts is far more accurate and less laborious than the method of making them to measure and fitting them upon the patient, and ought to replace the latter practically entirely except in the case of simple stock appliances such as caliper splints and side steels. It has the additional advantage that when once the cast has been taken it is possible to carry on and complete most of the work without another visit from the patient. In fact, it is often possible to complete the appliance entirely by fitting upon the cast.

The method of making a cast used by artists is not suitable for the

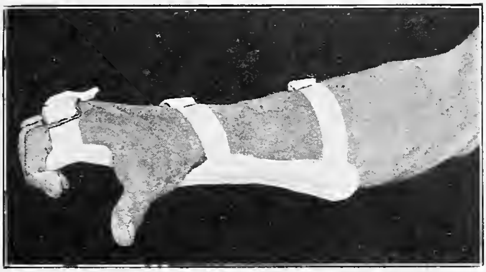

Fig. 137.—Completed plaster-of-Paris splint for the palmar surface of the wrist and fingers.

making of casts for surgical purposes. This method is to grease the part of the limb to be cast, and apply along it fine pieces of thread, arranged along lines which will divide the mould into sections which can be removed from the limb without breaking; for example, in casting a hand the thread is laid along the radial and ulnar borders of the forearm and hand, along the outer side of the thumb, over the tips of the fingers, and along the inner side of the little finger. Plaster cream is then mixed, and as it begins to thicken it is lightly thrown upon the hand to which it adheres. The hand is thus entirely enclosed in plaster. Just as the plaster has set the threads are pulled upon in the line of the limb, they cut out through the plaster and divide it into two halves, a dorsal and a ventral. When the plaster has set more completely the dorsal half is carefully lifted up and the hand removed. The two halves of the mould thus made can be fitted together, and when they have been filled the mould (the negative) can be chipped away, leaving a positive cast which is an exact image of the hand. The cast thus taken is of great use

as a record of the condition of the hand, and such casts are of course invaluable for this purpose. But they are not suitable for use for the making of splints. When a cast is required for the fitting of a splint it is often necessary to hold the limb in a particular position by external force; this makes the taking of a cast by this method impossible. Further, it is necessary to accentuate certain points, particularly bony prominences, upon the cast; this is only possible if the negative can be moulded upon the limb just as a plaster case is. The taking of plaster casts by this artist's method is difficult, only possible with long practice. Fortunately the taking of casts for surgical purposes is much more simple. The method shown in Figs. 138 to 142 can be learnt by any surgeon in a very short time.

Fig. 138.—Taking a plaster-of-Paris cast with bandages. The bony points on the limb have been marked out and the limb greased, the bandage is being applied, a piece of string being left beneath it. The photograph shows the method of folding back the plaster so that it is not drawn tight.

Any bony points on the limb are first marked out; for example, in the forearm the styloid processes and the olecranon are outlined with a moistened indelible pencil. The limb is then lightly greased with vaseline and arranged in the position in which the cast is required. The latter point is important. If a splint is required to extend the knee, the knee must be held in the fully extended position whilst the cast is being taken. A piece of string or of twisted picture wire is laid along the limb, preferably along a line which does not pass over any bony prominence. A plaster-of-Paris bandage is taken, soaked, and the first few inches cut off; it is then wound round the limb in exactly the same way as when a plaster is being applied, starting at one end with three turns, working to the other end, where three turns are given, and then back again. It is most important to apply the bandage very loosely, as any constriction will produce a

ridge on the inside of the negative. The plaster should be evenly applied and should not be thick; as a rule six or eight layers are sufficient; it must be carefully moulded upon the limb as it sets.

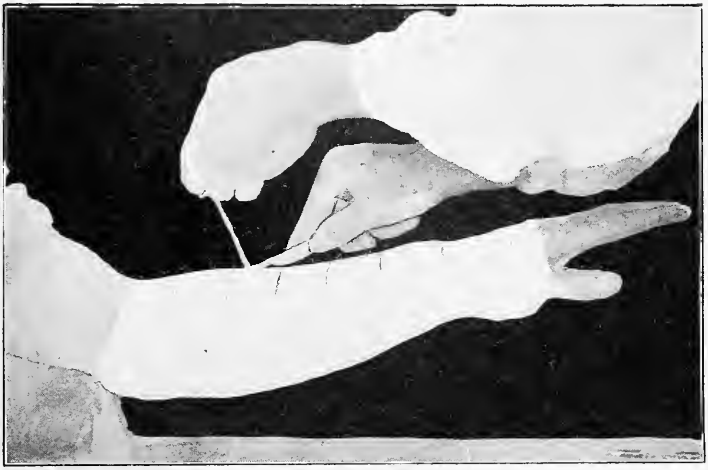

FIG. 139.—Taking a plaster-of-Paris cast. The plaster has set and is being cut up, after cross lines have been drawn. The further end of the string, which is held by an assisant, is not shown.

When the plaster has just set but is not yet quite hard it is ready for cutting; at this stage it cuts very easily with a sharp knife. A number of cross lines are first made across the part of the plaster

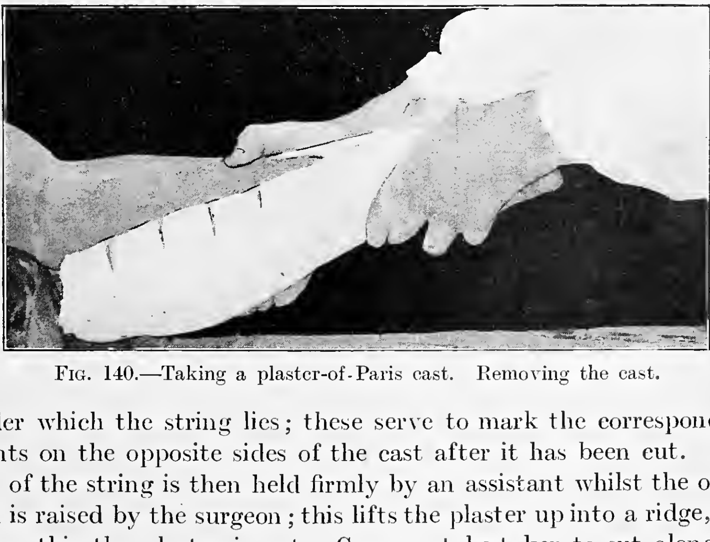

FIG. 140.—Taking a plaster-of-Paris cast. Removing the cast.

under which the string lies; these serve to mark the corresponding points on the opposite sides of the cast after it has been cut. One end of the string is then held firmly by an assistant whilst the other end is raised by the surgeon; this lifts the plaster up into a ridge, and along this the plaster is cut. Care must be taken to cut alongside

the string and not to cut it through. When the whole length of the case has been cut up, the raised edges are pressed back into place and the plaster allowed to set more firmly. Then the case is opened out and eased off the limb. It is immediately closed together, the lines along the cut being brought into apposition. The case is then lightly bandaged with a wet cotton bandage.

The mould thus obtained is a negative. It has next to be closed with another plaster bandage and filled with plaster cream, into this a strip of metal $\frac{3}{4}$ inch wide by $\frac{1}{8}$ inch thick is inserted, about four inches of this being left projecting from the end to serve as a handle.

FIG. 141.—The negative cast as removed from the limb.

When the cream has set completely the case is cut along the line of the original opening, and stripped off the inside, positive, cast. The latter is then complete, and only requires finishing before it is used as a model upon which a splint can be made. The positive cast must first be smoothed, any obviously adventitious irregularities being scraped away. Then plaster cream is mixed and a little moulded on over the bony prominences in order to mark them rather more, finally the whole case is smoothed down by rubbing in a thin layer of plaster cream. When leather is to be worked upon the cast it should be bandaged with a cotton bandage soaked in a thin starch emulsion; when this has set the cast is ready for the leather shop.

In the actual taking and making up of casts experience must

count for much. When a single segment of a limb has to be cast the method is easy. The string is laid along a straight line, preferably over muscle and not over any bony prominence, and the cutting and removal is easy. When the whole limb has to be cast there is no difficulty provided that the limb is straight, but when, for example, the arm and forearm have to be cast with the elbow flexed, it is difficult to cut around the joint and to get the cast off the limb. In this case the best method is to insert a double string, one along the outer side of the arm from the shoulder to the elbow, another along the outer side of the forearm from the elbow to the wrist; alternatively two strings may be inserted down the front and back

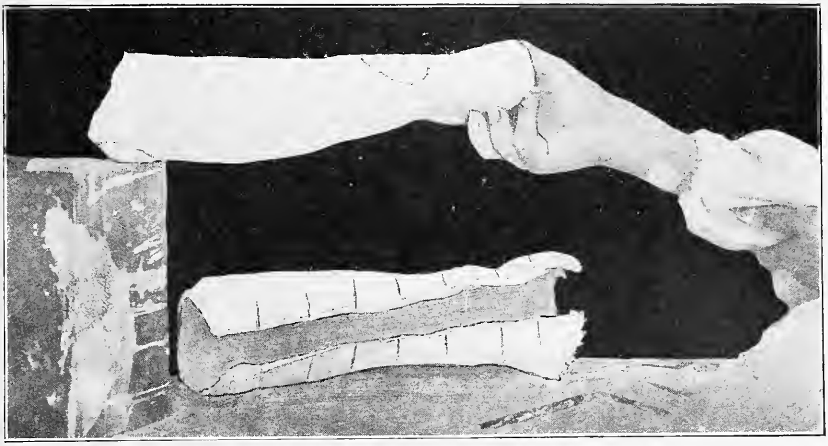

FIG. 142.—The positive cast removed from the negative, which is seen below. The marks made on the styloid processes and olecranon have come out on the positive cast and have been accentuated.

of the limb or along either side; the case will then be cut into two halves which are fitted together by adjusting the cross lines. In still more complicated cases—for example, when the whole upper limb and chest have to be cast—it may be necessary to take the cast in two or more pieces. First the body is cast, strings being inserted down the front and back. The two halves thus made are bandaged in place and the arm and forearm cast, this cast overlapping that of the trunk on the shoulder; pencil lines passing from the arm cast to the body cast enable the two sections of the mould to be fitted accurately together before the whole is filled. Such a cast should be left open until metal rods have been inserted into it, otherwise the plaster positive, without metal strengthening, will be too weak.

A removable plaster case is best made by the same method; for example, if a case for the thigh and leg is wanted a layer of tricot is

first pulled over the limb. two strings being inserted along the inner and outer sides. Then plaster-of-Paris bandages are applied until the case is sufficiently thick, and when these have set the case is cut off along each string. It is put to dry. strengthened with additional plaster or metal and used as a splint.

Plaster of Paris as a Correcting Agent.—In applying plaster of Paris as a purely retentive agent it is unnecessary to pad the limb beneath the plaster; when, however, local pressure is to be applied in order to correct a deformity, padding is essential, and great care will be required to prevent the production of sores. Whenever possible the points of pressure should be estimated and specially padded.

Fig. 143.—Verrall's supinating plaster.

If it is uncertain how the pressure will be distributed the whole limb must be padded. It will be simplest to take certain examples of the use of plaster in correcting deformities.

Verrall's Supinating Plaster.—When an injury of the elbow region or forearm which does not involve the bones has been kept in the pronated position, it may be extremely difficult to force the movement of supination. In certain cases it may be desirable to force supination when there has been a fracture, and in cases of excision of the head of the radius for synostosis of the superior radio-ulnar joint, and of separation of a synostosis of the forearm bones it is urgently necessary to alter the position from pronation to supination or vice versa soon after the operation. In all these cases the alteration of position is a difficult matter, solved however very easily by Verrall's method. It is necessary to keep the elbow flexed in order to provide a fulcrum

from which the twist may be applied. The pressure must be applied to the wrist and palm of the hand.

The limb is placed with the elbow at a right angle and the wrist extended. The lower half of the arm and upper half of the forearm is then enclosed in a layer of felt which is carefully fitted and sewn on. The lower half of the forearm and the palm of the hand, including the base of the thumb, is similarly covered. Then the upper section of felt is covered with a layer of plaster bandage, which is allowed to set, and the lower section similarly covered. Four pieces of metal are then taken; each consists of two arms at a right angle, one arm being 2 inches long, $\frac{3}{4}$ inch broad and $\frac{1}{16}$ inch thick,

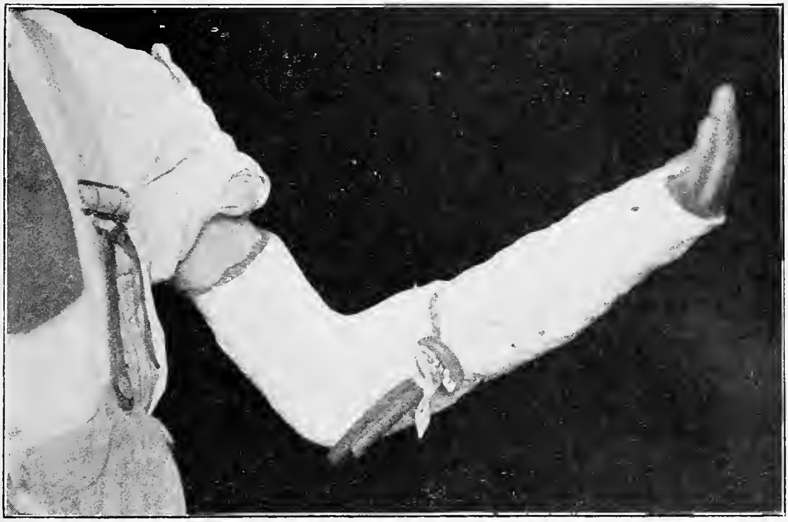

Fig. 144.—Verrall's supinating plaster.

and being notched at the edges to make it adhere in the plaster; the second arm is about 1 inch long and is not notched. Two of these pieces are laid in the upper section of plaster, the notched arms being applied to the plaster along the inner and outer sides of the forearm, the other arms projecting from the lower edge of the plaster. These pieces of metal are then incorporated in additional layers of plaster bandage. The other pieces of metal are similarly incorporated in the plaster along the sides corresponding to the radial and ulnar borders of the limb, the projecting arms being at the upper margin of the plaster. When the case has set firmly the metal projection on the radial side of the lower section is tied to that on the outer side of the upper section, and the projection on the ulnar side of the lower section to that on the inner side of the upper section. A force

tending to supinate the forearm is thus exerted. If pronation is desired the projections are tied in the reverse way. Pronation or supination can be obtained in a few days provided that the obstruction is not bony. It is advisable to maintain the new position for one or more weeks before the plaster is removed. If desired, e. g. after an operation for synostosis, the forearm may be held in pronation and in supination for alternate periods.

Finger-flexing Plaster and Splint.—This method is also due to Verrall. It is designed to assist in forcing flexion in fingers which are stiff in the extended position, specially when the metacarpo-phalangeal joints are hyperextended. The splint consists of a short cock-up splint with a small and narrow palm piece to which is attached an arm which projects in front of the wrist to end in a cross-bar situated exactly opposite the metacarpo-phalangeal joints; there is a second bar across in front of the wrist. This splint is fixed to the hand by plaster bandages, and the fingers are then tied to the further cross-bar with extension tapes which are fixed separately to each finger with strapping. By placing the cross-bar exactly opposite the metacarpo-phalangeal joints the counter pressure comes against the palm and front of the wrist, so that the splint is forced against this point and is not forced either up the forearm or down into the hand as it is if the pull is in the direction of the extended fingers or upwards towards the front of the forearm. In applying the splint the front and back of the forearm and hand are first covered with a layer of felt, which is sewn or bandaged on. The splint is then applied and fixed with a plaster bandage which should include the palm and the root of the thumb, being trimmed up so as to allow free movement of the thumb. Neither the cock-up splint nor the plaster must reach further down the palm than the transverse fold which marks the line of movement at the metacarpo-phalangeal joints. When the splint is applied a piece of 1-inch strapping is fixed down the back of each finger and up the front, a loop being left at the end through which a tape is passed; these pieces of strapping are secured by three circular strips, one around each of the phalanges. The tapes are first tied to the further cross-bar with sufficient tension to exert a continuous pull upon the metacarpo-phalangeal joints. They are untied daily and the fingers put through their full range of movement. When flexion of the metacarpo-phalangeal joints has been regained the tapes can be tied to the near cross-bar and movement in the inter-phalangeal joints thus forced.

Finger-extension Splint.—This is another of Verrall's methods. The splint consists of a dorsal bar which extends down the back of the forearm and projects beyond the end of the hand, where there is

a cross-bar; it has two plates, the upper of which rests upon the back of theforearm, the lower on the back of the metacarpal bones. The back of the forearm is covered with felt, which is bandaged on with a flannel bandage; it is fixed in place with plaster which includes the same amount of the hand as in the last splint. Extensions are fixed to the fingers in the same way and extension forced by pulling to the cross-bar. If the metacarpo-phalangeal joints tend to hyper-extend, a felt pad must be placed over the first phalanges.

Turner's Knee Splint.—This splint has already been mentioned in Chapter XVII. It consists of two plates which are incorporated in plaster of Paris which encloses the thigh and leg respectively. These are connected at the knee by a joint which is placed eccentrically in front of the joint. The whole of the thigh must first be enclosed in felt, which is fitted and sewn on. The leg and foot are dealt with in the same way. Plaster bandages are then applied to the foot and leg to within an inch of the upper margin of the tibia, and a second plaster is applied to the thigh. When the plaster has partly set the splint is applied on the outer side with the joint opposite but in front of the knee, the thigh and leg sections being adjusted at the correct angle to bring them into alignment with the limb segments. Strings are passed through the holes in the edges of the splint (see Fig. 127). These lie round the limb and are incorporated in the plaster which is next applied and which holds the plates of the splint in place; they serve to make the splint hold securely in the plaster. When the plaster has set the rack can be screwed up and the knee thus straightened gradually.

A MacIntyre splint for flexing the knee is applied in an exactly similar way.

Aitken's Foot-drop Plaster.—This is intended to correct a slight talipes equinus which is not sufficiently severe to necessitate tenotomy. If by means of it tenotomy can be avoided much has been gained, for there is no doubt that even a subcutaneous lengthening of the tendon causes a certain amount of permanent weakening of the limb.

A strip of metal $\frac{3}{4}$ inch wide, $\frac{1}{8}$ inch thick, and about 30 inches long is taken and bent so that it lies down the outer side of the leg, bends outwards above the malleolus, and then extends downwards to a point two inches below the heel level. Here it is bent at a right angle so that it crosses below the foot, it is then bent upwards on the inner side, curved in above the internal malleolus, and made to lie close against the inner side of the leg. The leg down to the malleoli, the dorsum of the foot and the anterior part of the sole are first covered with felt, which is bandaged on and a strong plaster-of-Paris case applied which includes these parts. When this has set

the plaster is cut away with a knife from the level of the malleoli, the whole of the heel and the sole as far forwards as just behind the heads of the metatarsal bones being laid bare, the plaster remaining over the leg, the dorsum of the ankle and foot and the anterior part of the sole. The metal is then placed in position and the space between it and the heel and sole stuffed with non-absorbent wool. Additional plaster-of-Paris bandages are then applied to hold the iron in position and to cover in its lower end and the whole of the heel padding. When the plaster has set the patient is encouraged to walk upon the limb. His weight rests upon the heads of the metatarsal bones, the heel being in the air. The leverage exerted by the body weight presses the heel down and tends to correct the deformity.

The correcting splints described above will serve as examples of methods of correction in plaster; some of them are very ingenious. Simple methods hardly require description. For example, in a mal-united fracture of the tibia the limb can be fixed in plaster with strong pressure upon the point of angulation and with counter pressure upon two points on the opposite side of the limb segment. These points of pressure and counter pressure must be well padded, and by leaving windows it may be possible to insert pads to increase the pressure, as is done in Abbott's plaster for correcting scoliosis. In arranging points of pressure and counter pressure it is important to make them as wide as possible and to avoid pressure upon bony prominences. For example, in a mal-union of the tibia with an angle convex inwards the pressure must be upon the bone just above this angle. The counter pressure below should be upon the subcutaneous surface at the lower end of the fibula, that above should be against the outer side of the knee, not against the head of the fibula. Both the foot and the knee joint should be included in the plaster.

CHAPTER XIX

PHYSIOTHERAPY

Physiotherapy may be taken to include treatment by baths, massage, passive movements, active movements and exercises, and by such special methods as light and heat baths, ionisation and diathermy, radium and X rays.

In the after treatment of wounds and injuries the objects of these forms of treatment are generally—

1. To soften and relax scar tissue.
2. To increase the range of passive mobility.
3. To increase the range of active mobility.
4. To improve the power, range of action and control of the muscles.

The first two aims are only means towards the attainment of the last two. There is little use in softening and stretching scars and increasing passive mobility if this does not lead in the end to improvement in active mobility and in function. In fact, an increased range of mobility may be a positive disadvantage if there is no muscular power. If the main principle that our aim is the improvement of function is lost sight of, treatment will often be unnecessarily prolonged and wasted.

In the chapter on stiff joints it has already been pointed out that great judgment is required in discriminating when it is desirable to force the movement in a damaged or stiff joint, and in deciding upon the correct method to be employed. Only experience can enable us to reach a right conclusion, and this experience necessitates a knowledge of the methods and uses of all forms of treatment as well as a sound conception of the pathology of the conditions to be treated. When the treatment is left entirely to someone who specialises in a particular physical method there is a real risk that this particular form of treatment will be used and persisted in despite the fact that it is not producing the best results. Therefore the surgeon who is responsible for the treatment of the patient should himself study the methods and results of massage and of the other forms of physiotherapy, meeting those who specialise in these forms

of treatment and discussing his patients with them. Only by this method will the best results be obtained.

It is impossible here to do more than outline the several methods of physical treatment so far as they apply to the after treatment of wounds and injuries, stating briefly their objects and the results that may be expected of them. For more detailed accounts works upon the special forms of treatment must be consulted.

Hydrotherapy.

The effects of baths used for such conditions as scars, fibrosis of muscles, adhesions and stiff joints depend upon (1) the temperature of the water used and (2) the movement imparted to the water. If the temperature of the water is high (105° F. or over) a hyperæmia results, and, after immersion for fifteen minutes or so, the limb is heated throughout and remains hyperæmic for a considerable time after removal from the bath. Movement of the water acts as a form of gentle massage which increases the hyperæmia produced and has also a slight mechanical effect by massaging, softening and stretching adhesions. The bath most often used is the whirlpool bath, in which the water is kept at a temperature of 105° to 120° F. and is kept in movement either by a running current, or by a turbine, or by a current of air. This is much used for the treatment of scars, adhesions and stiff joints, both as a treatment in itself and as a preliminary to subsequent treatment by massage and electrical stimulation. The hyperæmia produced assists the subsequent massage and mobilisation and improves the electrical reaction of the muscles. The subsequent electrical treatment is also assisted by the thorough soaking of the limb, which improves the penetration of the current. Passive movements may be carried out under water in the bath, being assisted by the hyperæmia and also by the analgesic effect produced both by the heat and by the movement of the water. Active movement in the bath may also be easier than it is normally, because of the buoyancy of the limb in the water. The effects of this bath are undoubtedly very largely due to the heat, and if a whirlpool bath is not available almost equal effects can be produced by the use of a simple hyperthermal bath which is kept up to the proper temperature, either by running in hot water from a tap, or simply by having a kettle of water near by and adding its contents to the bath from time to time.

In painful conditions, for example in painful lesions of the nerves, many forms of baths may be tried. Sometimes heat relieves the pain, sometimes cold. Gentle movement in a whirlpool bath will relieve the pain of a neuritis, or a low-pressure douche may do so.

The effects are very variable, and it is difficult to predict which particular form of treatment will suit any individual case.

When stimulating effects are required alternations of temperature may be useful. For example, when stimulation of the circulation is required in such conditions as the results of trench feet, contrast baths may be used, the feet being placed alternately in hot and cold water. When stimulation of a muscle or limb segment is required douches may be used with varying or alternating temperature.

Paraffin Baths.—The paraffin bath consists of soft paraffin kept at a temperature of 130° F. by means of hot-water pipes or by a water jacket. Immersion in this is easily borne in spite of the apparently high temperature; it produces a hyperæmia which is very persistent, the limb remaining red and sweating profusely for a considerable time after removal. This bath is used for the treatment of stiff joints, particularly for such conditions as stiffness of the hands from periarticular adhesions.

Hot Air and Radiant Light Baths.—These also are used for the hyperæmia produced, which is persistent. They are useful for softening scar tissue and adhesions and as a preliminary to massage and electrical treatment.

In general it may be said that treatment by baths has definite results in—

1. Causing local hyperæmia.
2. Producing the effect of gentle massage, through movement imparted to the water, and thus assisting in softening and stretching scar tissue, and also in producing an analgesic effect.
3. Stimulating the circulation and also the muscular tissue.

It should be prescribed and used with these definite objects in view.

Treatment by Massage.

Massage consists of certain definite manipulations with the hand. The classical methods are—

1. *Stroking or effleurage, i. e.* a gentle stroking movement carried out from the periphery towards the central part of the limb. The effects of stroking are—

(*a*) A sedative effect, amounting even to an analgesia.
(*b*) A mechanical aid to the circulation, and in addition a reflex improvement in the flow of blood.
(*c*) When the stroking is deep an improvement in the deep circulation as well as in that through the skin.
(*d*) A diminution in muscular spasm due to the analgesic effect.

2. *Kneading or petrissage, i.e.* a deep manipulation in which the muscles and other deep structures are moved beneath the skin which itself moves with the hand of the masseur. In addition to having effects upon the circulation similar to those of stroking, this manipulation stretches and mobilises deep scars and areas of fibrosis.

3. *Striking or tapotement*, either by beating with the open palm or by hacking with the ulnar border of the hand. This has a stimulating effect upon the circulation, and if carried out lightly and quickly also an analgesic effect.

4. *Vibration*, usually carried out with a pad or roller attached eccentrically to a hand or electrically driven motor. The first effect produced is numbness, then the limb becomes warm and hyperæmic.

It will be seen that the effects of massage may be classified briefly as—

(*a*) Analgesia, pain being diminished, and perhaps as a result muscular spasm lessened so that movement becomes easier.

(*b*) Increased vascularity, probably largely reflex in origin. This assists in the removal of effusions, and helps to soften scar tissue. Improved circulation may also assist in accelerating the healing of a wound, particularly if it has reached the stage of a chronic ulcer. It also increases the production of callus around a fracture.

(*c*) Mechanical effects, including the removal of effusions, the prevention of the formation of deep adhesions, more particularly those in muscles or between muscles, and the stretching of adhesions which are already in existence.

(*d*) Stimulating effects. That upon the circulation has been mentioned. By direct kneading or vibration over a nerve it is possible to cause a contraction of muscles supplied by the nerve. It is to be doubted, however, whether such methods serve any purpose in the treatment of wounds and injuries which cannot be more simply and more safely attained by other means.

It is best to consider massage separately from treatment by passive movements, with which it is usually combined; if this demarcation were more strictly made massage would not be so frequently blamed for ill effects that are usually due to forced movements applied in unsuitable cases or at the wrong time.

As already stated, the effects of massage are often assisted by preliminary treatment in a bath. Massage itself is used as a preliminary to passive movements and active exercises, and also as a

sequel to exercises, to improve the circulation and to assist the return of the tired muscles to the normal condition.

Massage in the Treatment of Unhealed Wounds and Ulcers.—A large granulating wound is often slow in healing, for reasons which are largely mechanical. The surface of the wound is covered with granulations and its margin covered with a layer of new epithelium. The granulations in their deeper part are becoming organised into fibrous tissue, and the marginal epithelium lies upon a layer of newly formed fibrous tissue. All this new fibrous tissue undergoes a slow progressive contraction, becoming in the process to a large extent devascularised. At the same time it shrinks in size. For a time this process of organisation of fibrous tissue and contraction goes on smoothly, the ulcer becoming smaller both because of the ingrowth of the epithelium and because of the shrinkage. But in a large wound sooner or later healing ceases, the central ulcer either remains unchanged in size or enlarges. The ulcer is now left in the centre of a scarred area, with scar tissue beneath it also. The contraction of the scar tissue has diminished the vascularity of the central ulcer and so interfered with its healing. Moreover, the progressive contraction is no longer able to draw in the wound from the edges, instead it contracts from the centre and so tends to open out the ulcer and to enlarge it. Of course such a process leading up to the production of a chronic ulcer may often be prevented or cured by skin grafting, or by excision of the wound and suture after under-cutting or by covering with a pedicle graft. But in many cases, particularly in the smaller wounds on the limbs, if the margins of the wound are massaged lightly from an early stage the fibrous tissue can be kept vascular and supple. The normal healing process continues to progress and the ulcer closes. Massage in such cases takes the form of gentle but firm manipulation of the marginal skin upon the deep-lying tissues. In order that it may have a good chance of success it should be commenced early before too large an area of scar tissue has formed.

Treatment by Passive Movements.

By passive movement is meant that a joint is put through its normal range of movement or through a part of this range by an externally applied force. Usually this force is exerted by the hand of the surgeon or masseur. In treatment by mechanical appliances of the Zander type the movement is carried out by a machine.

Passive movement may be unrestricted, for example in recent injuries, but yet it may be desirable to carry them out in order to preserve the full range of mobility. More often the movement has

to be forced because it is restricted by muscular action, by adhesions or scars, or by bone. In this case the term forced movement may be used. The question of the advisability of forcing movement has already been discussed in the chapter on stiff joints and in considering the disabilities of individual joints. It may be said that much of the disrepute of massage depends upon the injudicious use of forced movements.

As already stated, movements may be restricted by scarring of the skin or deeper tissues (including simple adhesions as a form of localised scar), by muscular action or by mechanical obstruction by bone. Only in the first class of case can forced movements do good, and even in these forced movements are often useless, sometimes dangerous. When movement is prevented by muscular action the muscles are on guard because the movement is painful. Most often this muscular action is an indication that there is some active inflammatory process, which should be considered to contra-indicate forced movements altogether. Sometimes when active signs of inflammation are absent the scar tissue is in a stage of active proliferation and contraction, and every time that it is stretched there is a further effusion, with more subsequent organisation and fibrosis. So that the frequent stretching only in the end gives rise to the formation of more scar tissue, with greater stiffness than ever. In other cases the muscular action is protecting a painful adhesion which is stretched by the movement. Daily stretching will then produce much pain, and often a subsequent increase of stiffness. If an anæsthetic is administered and the adhesion ruptured the pain disappears and the condition is cured almost at once. These various conditions require a nice discrimination in their treatment, the probable pathology of each having to be estimated and, as already stated, the idiosyncracies of the individual joints allowed for. Certain general rules may be laid down.

1. When mobility is restricted by muscular action the first question must be: Is there evidence of inflammation? If the answer is positive the proper treatment is rest and not passive movement.

2. In the absence of inflammation: Is there a localised painful adhesion? Or is there a more generalised fibrosis around the joint? In the former case movement under an anæsthetic may be indicated, in the latter a more gradual mobilisation by daily passive movements.

3. When mobility is restricted by scarring and fibrosis, passive movements may be started and persisted in. The force used should be sufficient to produce pain at the time, but not sufficient to induce a pain which persists long after the treatment is over. Nor should it be sufficient to produce an effusion or inflammatory

reaction. If no progress can be made with this amount of force, then it is time to try some other method, such as alteration of position of the joint on a splint with a rack or with an extension, or movement under an anæsthetic, probably followed by fixation in the new position until the inflammatory reaction produced has had time to subside.

Persistent attempts to increase movement which is blocked by bone are of course useless. It is to be feared that much time is, however, wasted upon such attempts in massage clinics.

The use of machinery such as Zander apparatus is in much favour in certain clinics. It may be confidently stated that this method has no advantages over the manual method, and certain definite objections. It is to be feared that it is often liked because it is showy and because it saves trouble. In most large clinics which have been fitted with Zander apparatus those pieces which carry out passive movements are little used, the more favourite pieces of apparatus being those which carry out active exercises. It is a fallacy to think that repeatedly stretching a stiff joint, perhaps fifty or a hundred times at one sitting, has any advantages. It is sufficient to put the joint through its movements three or four times at a sitting. The repetition of the movement does no good; it may, in fact, by inducing an inflammatory reaction, retard subsequent progress. It is simpler to carry out the movement with the hand three or four times than to fix the limb up in the Zander machine. A further criticism of machinery is that it is difficult or even impossible to fix the limb in such a way that the patient is unable to dodge the movement if it is painful. It is common to see a patient fixed in the apparatus, diligently allowing the movement to be carried out up to the point to which it is already free, and stopping it from reaching a point which will induce pain. Still a further criticism. The patient's muscles naturally resist any movement which will be painful; for example, if the machine is designed to flex the knee the quadriceps muscle naturally resists the movement, so that one effect of the machine is to give active exercise to this muscle during the whole period of treatment, assisting it in fighting against the increase of flexion. The movement designed to increase the range of flexion has done nothing except strengthen the extensor muscles. Zander apparatus has a definite use in active exercises, but even in this it is doubtful if it is as efficient as exercises carried out with simple Swedish gymnastic appliances, or even without apparatus at all.

Treatment by Active Movements and Exercises.

Exercise treatment is the most important of all forms of physiotherapy and at the same time perhaps the most difficult. It necessitates the active mental and physical co-operation of the patient, which is much less necessary in treatment by massage, baths, passive movements or electrical methods. This co-operation is both a difficulty and an advantage. The instructor must have a considerable power of control and persuasion, so that he is able to make his patients exert themselves in the right direction. If he has not this power no amount of technical knowledge of methods will avail him. At the same time technical knowledge is essential. Every instructor should be well grounded in the methods of Swedish gymnastics, the only scientific system of exercise work. And his knowledge should, if possible, not be confined to remedial exercise work, a general knowledge of educational exercises being a great advantage and giving him a much wider choice in his methods. As already pointed out, the object of all orthopædic treatment is the improvement of function; this is the ultimate aim of all methods of physical treatment, and it is only natural that the last stage of the restoration of function should be carried out by encouraging the functional use of the damaged part first by exercises and then by actual functional use in the course of work.

In starting a course of treatment by exercises it is essential that the disability should first be studied and a rational outline of treatment drawn up. A general table of exercises may greatly benefit the patient in himself, without however improving his local condition. In fact, its effect upon the latter may be actually harmful, by exercising muscles which are already strong and under good control and overstretching weakened muscle groups, or by encouraging postures which are vicious. For example, if a patient who has suffered from musculo-spiral paralysis and whose extensor muscles have only just begun to recover power is put to do exercises such as hanging and heaving which involve the powerful use of the flexors, the result may be actually to delay the full return of power. Again, it is essential for the instructor to have the full co-operation of the surgeon and to be informed by him exactly what movements may be forced or encouraged, and what return of mobility is to be expected. If such co-operation does not exist we may see attempts to improve the movement of a joint that is blocked by bone persisted in for an indefinite time, with no resultant improvement and with much consequent pain and discouragement to the patient.

The objects of exercise treatment may be briefly stated as follows :—

1. To increase the range of movement in a joint by utilising the patient's own efforts. Practically the methods of attaining this are two. First, to use the body weight as a means of passively forcing the movement, and secondly, to increase the movement by strengthening and improving the control of those muscles which bring it about. Examples of these methods will be mentioned later.

2. To bring into voluntary use muscles which exist in an unparalysed condition but which have been allowed to fall into disuse.

3. To improve the control of muscles which are used badly or insufficiently, particularly to bring muscles into action through their entire range in cases in which they have for long been used only through a short range.

4. To secure a return of the normal co-ordination of muscles and of muscle groups.

5. To strengthen individual muscles and muscle groups, and later to strengthen all the muscles of a limb and all the muscles of the body as a whole.

6. To improve the general physical powers of the patient, the effect worked for in training for any form of exertion. This latter object naturally leads up to the return of the patient to military drill or to his occupation.

Apparatus.—The use of apparatus is not essential for treatment by exercises, a clever instructor can accomplish much with little or none; but a gymnasium fitted with the ordinary stock pieces of Swedish apparatus is a great advantage. The appliances required are—

1. Sections of wall bars (ribstools).
2. A double beam.
3. Ropes for climbing.
4. Rings for hanging.
5. Reversible benches, which when turned upside down present a narrow surface upon which balancing exercises can be carried out.
6. A vaulting-horse, spring-board and mats.
7. Uprights and rope for jumping.
8. A high and a low plinth.

In addition certain special appliances are useful such as—

9. A nautical wheel.
10. A rowing machine.
11. A wrist-rolling machine, in which movements of flexion and extension of the wrist and of pronation and supination can be obtained.

12. Indian clubs (1 lb.) and light dumb bells.
13. Wands and tapered sticks of different sizes for grasping.
14. A long mat marked with parallel lines 7 inches apart for walking exercises.

And apparatus for games, such as—

15. Medicine balls.
16. A football and basket-ball apparatus.[1]

Methods of Treatment.—The possible methods of treatment may be best studied by taking examples. We may first take the case of a man who has sustained a compound fracture of the humerus, uncomplicated by any nerve injury, but with the limb stiffened and suffering from disuse, the result of prolonged splinting. Perhaps the finger-joints are stiff and the grip poor and incomplete, the wrist flexed and full extension impossible, the elbow flexed, extension being incomplete, and the shoulder movements generally restricted, abduction and external rotation usually being most defective.

The first step in such a case is to secure extension of the wrist; until this is complete it is impossible to improve the grip up to its normal. Then when the wrist extends freely and the grip has improved hanging exercises can be started to stretch the elbow and to improve the shoulder movements. The proper sequel of treatment is therefore to work in this case from below upwards, starting, however, with the wrist.

Of course it is possible to extend the wrist by the exertion of a passive force, either by daily stretching or by forcing it during anæsthesia, or by the use of a splint. These methods will be used in appropriate cases, but in other cases, particularly when the restriction of movement is slight, active exercises may be used entirely. A useful method is to utilise the exercise of prone falling. First of all, this will be carried out with the patient leaning against a wall or beam, so that only a proportion of the weight comes upon the hands. Then as extension improves the beam will be lowered, until the patient is able to rest his entire weight upon the hands resting upon the ground, the wrists being fully extended and the elbows as straight as they will come. Then the grip must be improved, exercises for gripping the bars of the ribstool and for gripping a tapered stick can be carried out, the stick used being smaller and smaller. As soon as the grip is sufficiently strong the patient may

[1] It is impossible here to enter into details as to the nature of this apparatus or to describe the individual exercises. Those who are unfamiliar with Swedish exercise methods should study the appliances used in a gymnasium, where they may also learn the methods of carrying out the exercises. The principles upon which exercises are designed and exercise tables drawn up may be best studied in the Army and Navy Manuals of physical exercises.

be made to hang from a ribstool, and the weight of the body thus used to stretch the elbow and shoulder. Finally, exercises such as span-bending and hanging with the back to the ribstool will complete the mobilising of the shoulder.

Patients who have sustained an injury to the knee joint or a fracture of the femur are frequently sent to the gymnasium at a stage when the movements of the knee are incomplete. Usually extension is complete but weak, flexion limited. Treatment by exercises will be most successful if it is started as soon as flexion of the knee reaches the right angle. The two points to be worked for are increased flexion and additional strength in the quadriceps extensor muscle. A useful exercise in the early stages is the following. The patient hangs to one bar of a ribstool, placing his feet upon a lower bar, he then alternately extends and flexes the knee. During extension the quadriceps is actively exercised, during flexion the weight of the body forces the movement of flexion. If the hands and feet are far apart the movement is small, the work done by the quadriceps is not great, and flexion is only forced through a small range and by a portion of the body weight. The exercise is increased in severity by bringing the hands and feet nearer together, until when they are separated only by a few bars of the ribstool, flexion is complete and the strain upon the quadriceps is very great. The principle of increasing the severity of an exercise by altering the position in this way is called *progression.* When knee movements are fairly free the exercise of kneeling trunk backward falling may be used. In this the patient kneels down with the trunk upright and the hands upon the hips. He then allows the whole trunk to fall backwards as far as possible, keeping the hips and back quite rigid, and slowly recovers from this position. In this exercise the whole weight of the trunk forces the flexion of the knees, and at the same time the quadriceps muscles have to do work to prevent the trunk falling too far. It assists, therefore, both in stretching the knees and in strengthening the quadriceps.

A further exercise which is almost indispensable for knee cases is the following. The patient stands with feet together and toes turned slightly out, hands upon hips. He rises slowly upon the toes and then bends the knees slowly, sinking into a squatting position until, if the movement is completed, the buttocks reach the heels. He then slowly rises again until he is standing with knees straight upon tiptoe. This exercise (tiptoe, double knee bend and stretch) is an example of an exercise carried out in a *balance* position, that is to say, in a position in which balance is difficult. That is to say, quite apart from the work which the muscles have

to do to carry out the actual movements, they have to be kept constantly under control in order to preserve the balance of the body. In the case of knee movements, extension is carried out by the main mass of the quadriceps, but the vastus internus, the lower part of which passes outwards to its insertion to the patella, is particularly concerned in bracing up the knee joint and in preserving the balance. In this exercise the vastus internus is specially exercised, it may almost escape use in the simpler movements of extending the joint. The recovery of power in the vastus internus is essential to the attainment of a really secure knee joint, and for this reason this exercise is particularly useful.

In many cases patients are sent to the gymnasium at a stage when movements of the damaged limb are practically complete, but functional use is very imperfect. General exercise tables are then useful, and games serve a special purpose in inducing the men to forget their disabilities and to use the damaged limb in a natural way. The organisation of games for this purpose is a very important part of the work of the gymnastic instructor. Purely functional disabilities may also be well treated by means of games. If the patient can once be induced to become interested and excited in the play he is likely to forget his disability altogether and to recommence the use of the disabled limb.

Electrical Treatment.

Methods of electrical treatment are so numerous and so complicated that the surgeon, who perhaps has small knowledge of electrical apparatus, is apt to be discouraged and inclined to leave the details of treatment entirely to those who engage in this specialty. This is quite unnecessary. In almost all cases the form of electrical treatment that the surgeon requires is a simple one. It consists of muscle stimulation, either by means of a faradic current when the muscles to be worked react to this current, or by a galvanic current when the muscles show the reaction of degeneration. These methods are easily learnt, and the surgeon can at least understand the treatment that is being applied to his patients and can judge whether it is doing what he wishes.

This form of treatment necessitates the treatment of each patient by an individual masseuse. It is impossible for one masseuse to overlook a number of treatments at one time. For this reason many electricians have come to use other forms of treatment which can be carried out without individual work, for example, faradic, galvanic or sinusoidal baths. It may be stated at once that these rules of treatment in most cases are not what the surgeon desires. If we take as an

example the case of a group of muscles paralysed owing to section of the nerve which supplies them, the surgeon wishes for electrical treatment during which each of these muscles will be made to undergo a series of contractions, so that their condition may be kept good until time has passed which will allow of the regeneration of the nerve. This is only possible by individual stimulation of the muscles. It is true that if the limb is inserted into a bath and an interrupted galvanic current is passed through the water, alternate contraction and relaxation of the affected muscles will result. But by this method the opposing muscles will also be stimulated, and by strengthening these the tendency to the production of a fixed deformity is increased. Further, it is a principle of the treatment of paralysed muscles that they shall be preserved from overstretching. When in a bath this is impossible, and in fact the stimulation of the opposing muscles is almost certain to produce this effect.

To take a second example, often the action of a muscle is interfered with by the passage of it or its tendon beneath a scar. Our desire then is to produce contractions in the muscle and so to strengthen it and to work it free. The only electrical method of doing this is to stimulate the muscle individually. Or an injury may have resulted in a weakness of a particular muscle, as in the case of the vastus internus in injuries of the knee joint. This muscle can then be strengthened by deliberately making it work by faradic stimulation at its motor point; this effect cannot be brought about by any other electrical means.

The individual excitation of muscles with the faradic current can also be used as a means of re-education. In many functional disabilities it may be said that the patient has forgotten how to use the affected muscles. When he is able to see the action of the muscle as produced by stimulation he is able to imitate this movement. Similarly when a muscle has been transplanted the patient may be taught its new use by seeing it work as the result of stimulation. In using the faradic current in this way it is essential to follow up the electrical treatment by some re-educational exercises. In order that this may be done the treatment should be administered by a masseuse who has been trained in the action of muscles and in the use of remedial exercises.

For the details of electrical methods of treatment reference must be made to works upon this specialty. Briefly, it may be said that a simple galvanic switchboard with metronome interruptor and a Bristow galvanic coil is sufficient for almost all treatments, and that the essential points for the masseuse to study are the care of this apparatus, the action of the individual muscles and their motor

points. For faradic stimulation the Bristow coil is both simpler and more comfortable for the patients than any other apparatus; in addition, the stimulus given and the consequent contraction of the muscle can be regulated with the greatest ease. In this coil the stimulus is administered not by making and breaking the current, but by inserting a heavy core into the centre of the coil. The insertion of the core by increasing the induced current in the secondary coil gives the stimulus to the muscle, the removal of the core by diminishing the current allows the muscle to relax. The current thus surges up and down, and the stimulus is not a sudden sharp one, as when a make-and-break are used, but a gradual one. Faradic treatment can be administered with this coil to quite small children without causing pain or alarm.

Functional Re-education by Work.

The final stage of treatment of the disabled man consists in his re-education for actual work. In the case of men who are returning to the army this re-education consists in a return to military drill. In the case of men who are unfit for further service it consists in a re-education either for their former trade or for a new occupation if they are no longer fit for the work that they previously did. But before men can return either to military drill or to a school of technical instruction they must have practically finished their treatment. It is theoretically possible for them to start drill or occupational training whilst they are in hospital or in Command Depots, but there are practical difficulties in carrying this out. At the same time it is most important that the men should be kept occupied so far as is possible during that portion of their hospital treatment during which they are able to work, and it is also useful to induce them to work with their injured limbs as soon as this is possible. It is for this reason that workshops in which the men can work are so useful in orthopædic hospitals. They serve both as means of securing functional use of the damaged limbs and as a means of keeping the men occupied and encouraging them with the proof that they are capable of productive labour. Considered from the point of view of functional re-education there are two methods of using these curative workshops; each method has its advantages. In the first method the workshops are designed as a purely curative organisation, each man being put to do particular work which will exercise his damaged part and exercise it in such a way as to improve mechanically those functions which are interfered with. The work is not necessarily productive, and any individual item of work done by the man does not necessarily leave a tangible proof that he has turned out a

finished piece of work. In the other method the man is put into the shop for which his previous training will fit him. If he is a smith he works in the forge, if he is a fitter he works at splint or appliance making, if a carpenter he works in the carpenter's shop making splints, crutches, frames for suspending fractures, etc. He is induced as far as possible to use his damaged member, but no special care is taken to see that he is using it in such a way as to restore lost functions; practically the general use of the limb is aimed at rather than the use in any one direction.

The defect of the first method is that it is uninteresting. The man does not feel that he has produced anything, or that he is helping with the work of the hospital. The defect of the second method is that it does not aim at the restoration of lost functions by direct means. It is, however, by far the more interesting method for the men, and its psychological effect is great. By utilising the second method and choosing the work which is given to each man carefully very excellent results are attained.

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